COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 77

THE TERTIARY GEOLOGY OF THE BOULIA REGION, WESTERN QUEENSLAND

BY

R. J. PATEN
(GEOLOGICAL SURVEY OF QUEENSLAND)

Issued under the Authority of the Hon. David Fairbairn,
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DEPARTMENT OF NATIONAL DEVELOPMENT

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SUMMARY

Large areas of Tertiary sediments confined to four tectonically controlled sedimentary basins occur partly within the Boulia, Glenormiston, Springvale, and Mount Whelan 1:250,000 Sheet areas in far western Queensland. Carbonate, argillaceous, and arenaceous sediments and siliceous sinters were deposited. Fossils occur throughout, but are rare except in one basin. One deposit has been lateritized, another silicified to billy, and the remainder partly silicified to chalcedony and common opal; all silicification post-dates the laterite.

INTRODUCTION

This report is based mainly on the author's mapping and observations as a member of the 1957-59 joint field parties of the Bureau of Mineral Resources and Geological Survey of Queensland, which mapped the Boulia, Glenormiston, Springvale, and Mount Whelan 1:250,000 Sheet areas in western Queensland (Fig. 1). Relevant parts of adjacent areas were briefly examined.

During the mapping project, extensive areas of superficial Tertiary sediments were mapped and their considerable extent beyond the area of operations established. Four main areas of Tertiary lacustrine deposition, one of which is of possible fluviatile origin, were recognised (Fig. 2):

1. Springvale Basin
2. Marion Basin (possibly fluviatile)
3. Austral Downs Basin
4. Noranside Basin

Scattered siliceous spring deposits also occur in the region. Argillaceous and carbonate sediments were laid down in the Springvale Basin, arenaceous sediments in the Marion Basin, and carbonates in the Austral Downs and Noranside Basins. Other small carbonate deposits occur in the Breadalbane and Toko Range areas. Small Tertiary basins also occur at Old Cork and elsewhere to the east of the Boulia region (W. Jauncey, pers. comm.).

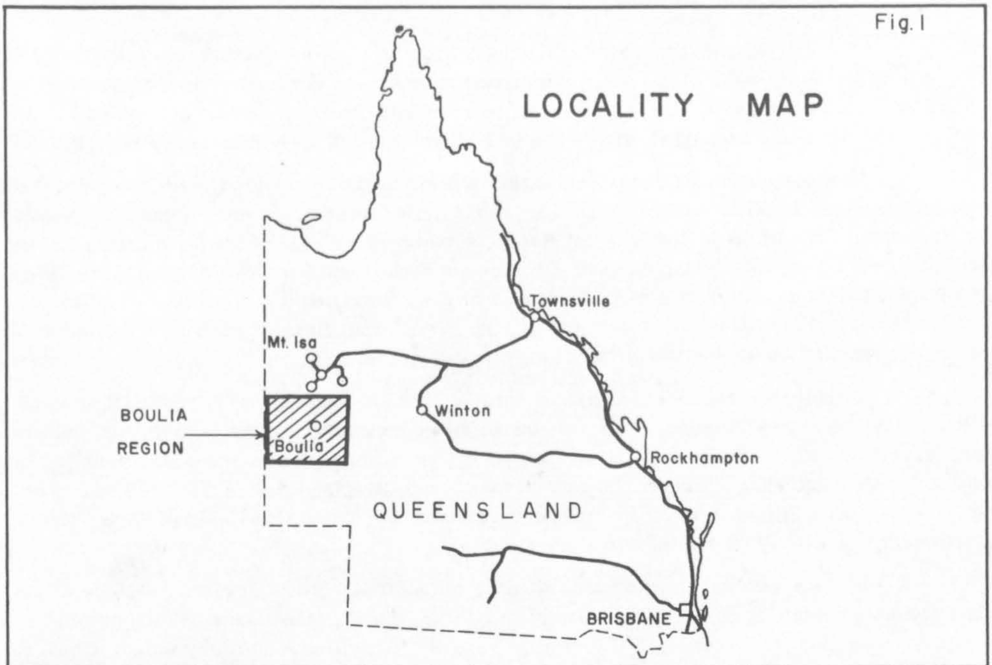
Disscussions of the basins refer mainly to those parts within the area mapped; only the Noranside and Springvale Basins lie wholly within that area. The development of billy on the Marion Formation is discussed in detail.

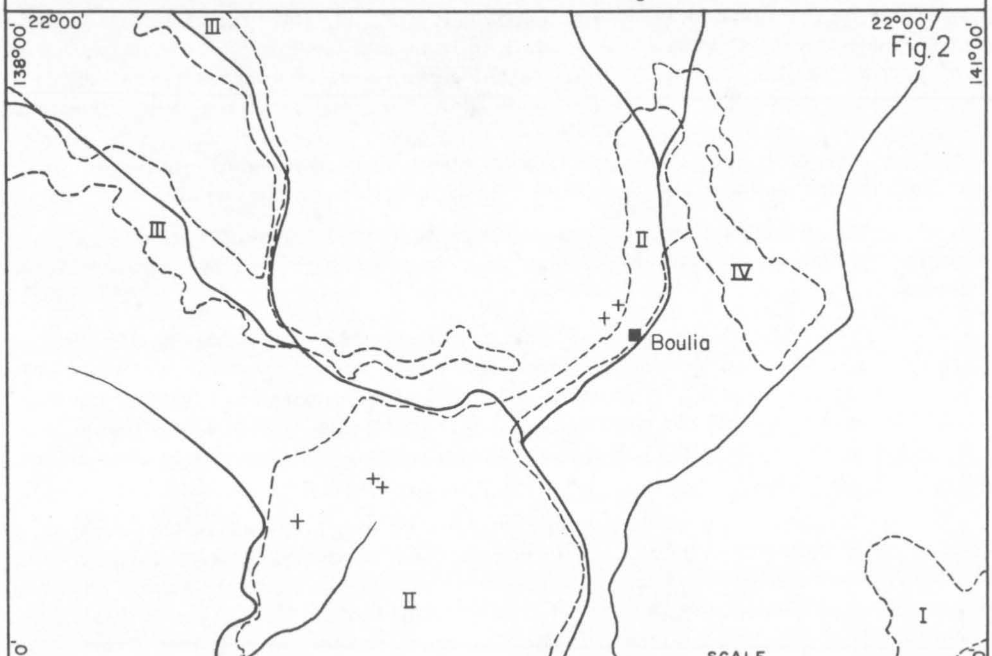
SPRINGVALE BASIN

The Springvale Basin was a small isolated basin developed superficially within the Great Artesian Basin in the Springvale area about 80 miles south-east of Boulia.

Casey (1959), after a short reconnaissance traverse in the area, named the sediments within this basin the 'Springvale Formation' and described them briefly. The type area was given as 'in flat-topped hills two miles south-west of Springvale homestead', with a reference section 'in the hills south of Junction Yard, 16 miles south-south-east of the homestead'.

The lithologies described were 'red vuggy sinter over hard grey sinter containing biscuit-like vuggy spring nodules, over silicified fine sand', and elsewhere 'chert with ostracods and gastropods, dense siliceous (?) dolomite and greenish chert'. Later, more detailed, mapping has shown that two unconformable units are included in the 'Springvale Formation', and the sediments are now redefined as: (a) Springvale Formation, the older unit, typified by Casey's type locality, (Paten (1960) used the name in this sense) (b) Horse Creek Formation, the younger unit, to which Casey's reference section belongs.





I Springvale Basin
II Marion Basin
\+ Siliceous Spring Focus
III Austral Downs Basin
IV Noranside Basin

Springvale Formation (Paten, 1960)

The Springvale Formation is named after Springvale Station, a cattle property about 80 miles south-east of Boulia. Springvale Homestead is situated on the east bank of Spring Creek, a tributary of the Diamantina River, at Lat. 23° 33'S and Long. 140°42'E. The type area is in red flat-topped hills 2 miles south-west of the homestead (Pl. 1, Fig. 1).

The formation extends from 4 miles north of the homestead, south as scattered low hills for about 22 miles to Uka Tank, and from 3 miles west of the homestead east-south-east for about 27 miles to the Goyder Range on the western side of the Diamantina River. Throughout the Springvale Basin the post-Cretaceous rocks form a plateau which stands above the surrounding sand and soil plains developed on the underlying Artesian Basin sediments. The Springvale Formation is blanketed by the overlying Horse Creek Formation but is extensively exposed by dissection of the younger rocks (Figs. 3, 4, 5).

Lithologies represented are a suite of iron-stained siliceous rocks, limestone, swelling clay, and rare sandstone. The iron-stained siliceous rocks are the commonest and are fine-grained, harsh to the touch, dense and rarely porous. Owing to irregular mottling by iron oxide, they are characteristically brightly coloured, ranging from pinkish red to cream. The iron-stained siliceous rocks are best exposed on the eastern side of Spring Creek immediately to the south of Springvale Homestead.

In thin section these rocks display a uniform texture of clotted opaque silica with varying amounts of brownish iron-oxide staining. Sand grains are rare and commonly the grain margins are replaced by opaline silica. Silicified secondary (concretionary) textures may be preserved in the clotted matrix (Pl. 1, Fig 2). Rare remnant areas of crystalline calcite occur, and the clotted matrix in some sections has a texture suggestive of that of mosaic calcite. At S148, about 16 miles south-south-east of the homestead, these siliceous rocks grade into fine-grained grey limestone, and unaltered parent limestone crops out at S145 in the same area. It is fine-grained, grey, and crystalline, with small clots of fine lime carbonate, and is characterized by rosette and cruciform calcite recrystallization. Thin-shelled molluscan fragments occur in the limestone at this locality.

This siliceous suite is hence the product of chemical alteration of the predominantly limestone portion of the Springvale sequence, though some may be altered calcareous clay.

Grey algal limestone and limestone beds (Fig. 3), containing thin-shelled gastropods, crop out in the western part of the area underlain by the formation. Practically all this material is replaced by brownish and bluish silica ranging from lustrous translucent to dull opaque, so that the outcrops are in fact chert, consisting of a very fine micromosaic of quartz (Pettijohn, 1957, p.432). The silica commonly preserves the original clotted texture of the limestone.

Clay, with rare sandstone and limestone lenses, crops out in sequences up to 60 feet thick in the western part of the formation, but is not common east of Spring Creek. The clays are brownish, greenish, and grey in colour and disperse rapidly in water. The best exposure occurs at S151 in the type area (Pl. 1, Fig. 1) and similar clays occur in small hills on the east side of Gum Creek on the road from Springvale to Diamantina Lakes. Clays from the type area swelled to three times their volume when tested in water. Near S145 on the west side of Spring Creek, hard clay with a white efflorescence of magnesium chloride on weathered surfaces crops out. Analysis of this clay by the Queensland Government Chemical Laboratory gave (Analysis 1569/59 G.S.):

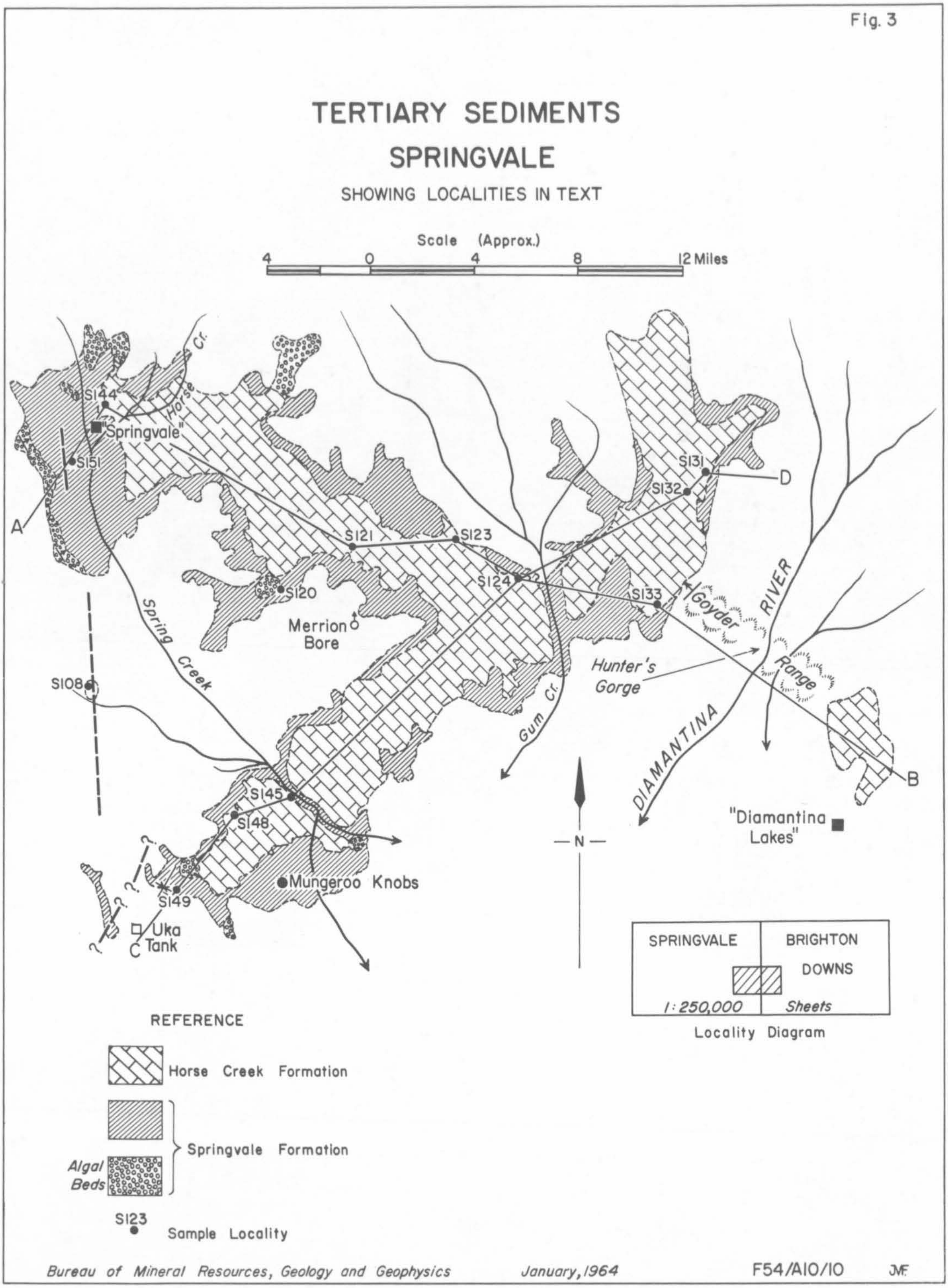


Fig. 3
TERTIARY SEDIMENTS
SPRINGVALE
SHOWING LOCALITIES IN TEXT
Scale (Approx.)
4 0 4 8 12 Miles
S144
"Springvale"
Horse Cr.
S151
A
S121
S123
S131
S132
D
S124
S133
S120
Merrion Bore
Spring Creek
S108
Goyder Range
RIVER
Hunter's Gorge
Gum Cr.
DIAMANTINA
B
S145
S148
"Diamantina Lakes"
N
Mungeroo Knobs
S149
Uka Tank
C
SPRINGVALE
BRIGHTON DOWNS
1:250,000 Sheets
Locality Diagram
REFERENCE
Horse Creek Formation
Springvale Formation
Algal Beds
S123
Sample Locality
Bureau of Mineral Resources, Geology and Geophysics
January, 1964
F54/A10/10
JMF

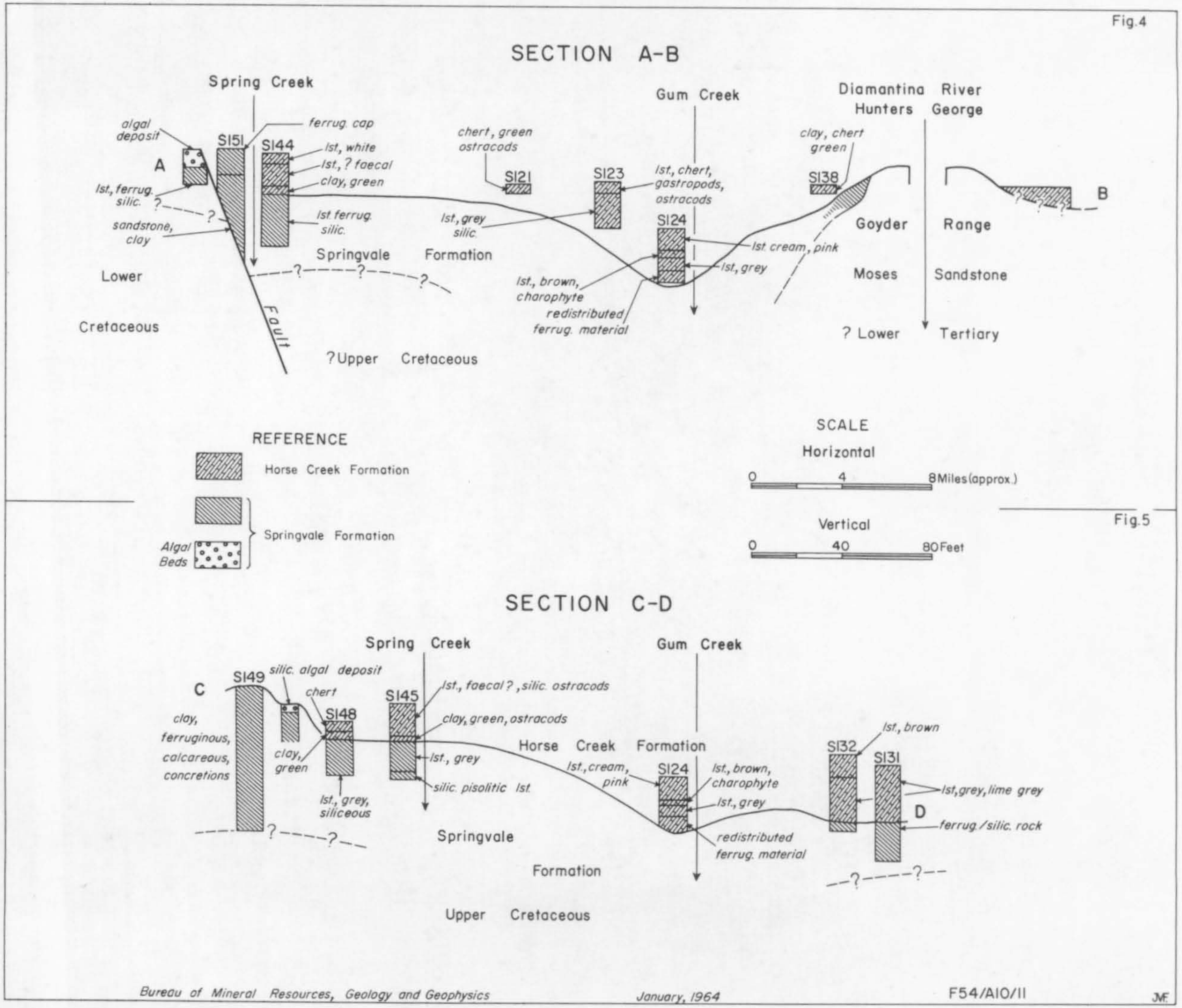


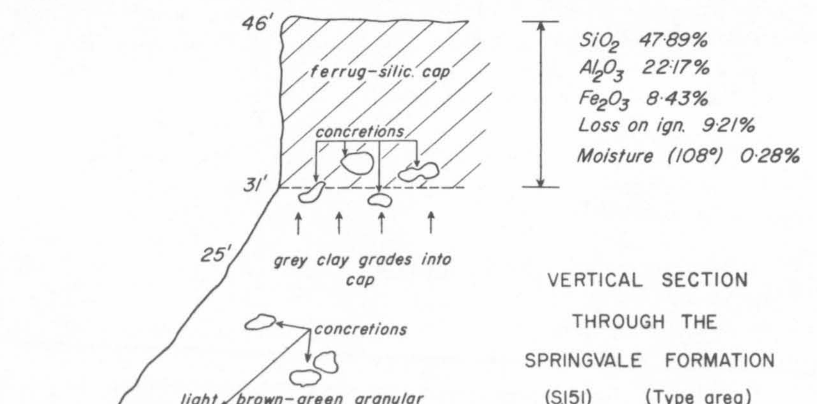
Fig.4
SECTION A-B
Spring Creek
Gum Creek
Diamantina River
Hunters George
algal deposit
A
lst, ferrug. silic.
sandstone, clay
S151
S144
ferrug. cap
lst, white
lst, ? faecal
clay, green
lst ferrug. silic.
chert, green ostracods
S121
S123
lst, chert, gastropods, ostracods
lst, grey silic.
S124
lst cream, pink
lst, grey
lst, brown, charophyte
redistributed ferrug. material
clay, chert green
S138
B
Goyder Range
Moses Sandstone
? Lower Tertiary
Springvale Formation
Lower
Cretaceous
Fault
?Upper Cretaceous
REFERENCE
Horse Creek Formation
Springvale Formation
Algal Beds
SCALE
Horizontal
0 4 8 Miles (approx.)
Vertical
0 40 80 Feet
Fig.5
SECTION C-D
Spring Creek
Gum Creek
C
S149
silic. algal deposit
chert
S148
S145
lst, faecal ?, silic. ostracods
clay, green, ostracods
lst, grey
silic. pisolitic lst
clay, ferruginous, calcareous, concretions
clay, green
lst, grey, siliceous
Horse Creek Formation
lst, cream, pink
S124
lst, brown, charophyte
lst, grey
redistributed ferrug. material
S132
S131
lst, brown
lst, grey, lime grey
D
ferrug./silic. rock
Springvale
Formation
Upper Cretaceous
Bureau of Mineral Resources, Geology and Geophysics
January, 1964
F54/A10/11
JMF

	Percent
Loss on ignition	15.1
Silica (SiO_2)	55.6
Alumina (Al_2O_3)	12.9
Ferric oxide (Fe_2O_3)	3.6
Calcium oxide (CaO)	7.5
Magnesia (MgO)	4.6
	99.3

Chemical alteration has also affected the clay sequences. This is illustrated in red-capped mesas on the western side of Spring Creek, e.g. in the type area (Pl. 1, Fig. 1). These red caps occur nowhere else in the Springvale area and are different from the alteration products of the limestone.

Figure 6 shows the sequence at S151 (type area) where the red cap is developed on a clay sequence. The pinkish red cap rock consists of an extremely porous fine siliceous boxwork densely impregnated by red iron oxide. It is 15 feet thick and grades downwards into light brown puggy swelling clay. This overlies a light brown to green clay in which aggregation has produced a granular texture. Concretions occur throughout the sequence as well as in the altered cap; near the base of the section, a thin band containing septaria occurs. At the northern end of the S151 mesa limestone concretions and lenses are commoner in the clays. Here a more open siliceous boxwork was developed in the cap, into which the limestone, densely iron-stained, persists. The softer material of the red cap has been powdered and used locally as a pigment for brown oil paint.

Fig. 6



VERTICAL SECTION THROUGH THE SPRINGVALE FORMATION (S151) (Type area)

Bureau of Mineral Resources, Geology and Geophysics   January, 1964   F54/A10/12   J.F.

Calcareous concretions are the commonest secondary structures in the Springvale Formation and occur within both the limestone and the clay, ranging widely in size and form. In the limestone their diameters range from 0.8 to 0.4 mm. With rare exceptions they are simple spherical bodies showing little concentric or radial structure, and have a fine even-grained texture. Nuclei are rare, but at S108 to the south of Springvale, numerous ?molluscan shell fragments occur in the concretions. Differential silicification commonly affects the concretions but not the matrix, so that they stand out on the weathered surface of the rock. The silica is light brown, opaline, and is not isotropic owing to the inclusion of finely disseminated calcite particles.

In the clays the concretions range up to 2 feet in diameter and are grey to brown. Some are simple spherical bodies, but most are compound forms.

Septaria occur in the clay sequence at S151. They are light brown disc-shaped argillaceous-calcareous bodies with a reticulate to finely nodular ornamentation. The diameter ranges from 2 to 6 inches. Internally the septaria contain radial and concentric syneresis (shrinkage) cracks; most of the cracks have a papery coating of white, finely crystalline quartz with most of the void space free of deposit (Pl. 2, Fig 1), but more rarely the void space is filled with interlocking quartz crystals up to 1/4 inch long (Pl. 2, Fig 2.). The material of the septaria is dense towards the outside but becomes porous towards the centre.

Secondary structures intermediate in form between concretions and true septaria occur. These resemble solid concretions externally but have a poorly developed internal syneresis system (Pl. 3, Fig 1).

Spherulitic recrystallization of calcite occurs in the limestone and calcareous concretions in the ferruginized parts of the deposit. This type of recrystallization appears to be a late-stage process and post-dates all previously formed secondary structures. Thus spherulitic calcite forms around small concretions, cuts across concretion boundaries, and expels iron oxide to areas peripheral to the crystal growth. This type of calcite growth forms regular or compound spherical bodies, or is irregular in shape.

These post-depositional structures form in a definite sequence which persists throughout the deposit and can be summarized as follows:

1. formation of concretions;

2. differential silicification of some concretions by opaline silica;

3. ferruginization;

4. spherulitic calcite recrystallization.

Plate 3, Figure 2 illustrates this sequence. It figures a fine-grained limestone with small calcareous concretions (lower right) that have been partly replaced by opaline silica. The concretions and groundmass are lightly mottled by brown iron oxide. A large, compound, coarsely spherulitic calcite body of later origin (centre) cuts across the concretions and is surrounded by a rim of dark iron oxide apparently expelled by the recrystallization. The central area of the spherulite is slightly stained by iron oxide, but the peripheral area is clear and strikingly free of it. This outer clear zone adjacent to the excluded iron oxide rim is a constant feature of spherulitic growth in the formation.

Plate 4, Figure 1 is an example of spherulitic calcite growth in a previously ferruginized large calcareous concretion. The spherulitic crystallization was apparently initiated at a number of points and growth proceeded inwards as though into a cavity. The iron oxide of the rock (dark) appears to have been expelled by crystal growth into the central area. As before the spherulitic area is slightly iron-stained and the clear zone adjacent to the excluded iron oxide well shown. Plate 4, Figure 2 is a further example of late-stage recrystallization (non-spherulitic) in a ferruginized limestone. Crystallization has expelled iron oxide to the intercrystal areas.

The Springvale Formation was chemically altered by leaching (particularly of lime), silicification, and ferruginization. It is evident that lithology controlled the end products, for whereas the clays produced strongly ferruginous-siliceous rocks, the dominantly limestone lithology produced lightly iron-stained dense siliceous rocks. However, the end products are analogous: both consist principally of iron oxide and silica, the difference being only in the form and ratio of the constituents.

The chemical events are most simply explained by relating them to lateritization: lateritized Cretaceous sediments are extensive and occur within a few miles of the Springvale area. Fisher (1958) stated that typical laterite profiles in northern Australia consist of an upper derived soil zone, overlying a ferruginous zone, overlying a mottled zone, overlying a pallid zone, overlying fresh rock, with a siliceous zone occurring anywhere in the mottled or pallid zone. The red-capped hills in the type area exhibit a distinct zonation. The upper ferruginous-siliceous cap passes downwards into irregularly coloured red, brown, and green clays (Fig. 6). These two zones are analogous to the ferruginous and mottled zone of a laterite profile. The irregularly iron-stained siliceous rocks (from the dominantly limestone sequence) may represent the mottled zone of an eroded profile. However, the anomalous occurrence of large amounts of silica and calcareous rocks in these profiles must be explained.

In general, in this part of Western Queensland, the laterite profiles have unexpectedly high silica values throughout, when compared with those that would be expected from the 'theoretical profile' (Reynolds, 1960); but whereas the profiles on the surrounding Cretaceous rocks appear merely indurated by silica, the silica in the Springvale 'profile' forms a distinct silica rock. Furthermore, the preservation of calcareous concretions and small limestone bodies in the profile is unusual, since it would be expected that alkaline earths would be removed during lateritization. The alteration product of the limestone from the Springvale Formation (silica rock) is unlike those on other limestone sequences (e.g. in Playford, 1954).

The Springvale profile is considerably thinner than the lateritic profile developed on the Cretaceous sediments of the region. This suggests that the Springvale Formation may not have been exposed throughout the full cycle of lateritic weathering. Possibly the Springvale Basin was not initiated until a late stage of the lateritic cycle. If so, material subsequently deposited in the basin would consist of the products of the erosion of the immature lateritic profiles on the surrounding shales and limestones and possibly also the by-products of the leaching of the surrounding region by the prevailing lateritic weathering. Reworked lateritic material would ultimately have constituted much of the Springvale Formation and this, plus its subsequent exposure to weathering only late in the lateritic cycle, may account for the anomalous nature of its weathering profile.

The greatest exposed sequence of the Springvale Formation is in the Mungeroo Knobs to the east of Uka Tank, where 70 feet of granular concretionary clay crops out. The

Formation thins towards the east against the Goyder Range, where it overlies Moses Sandstone of probable Lower Tertiary age (W. Jauncey, pers. comm.) (Fig. 4).

Horse Creek Formation (Paten, 1960)

After chemical alteration and erosion of the Springvale Formation, the Springvale Basin became a depression in which lacustrine limestone, the Horse Creek Formation, was deposited. The basin migrated several miles to the east so that it overlapped the older Tertiary rocks to the east of the area of deposition of the Springvale Formation.

Horse Creek Formation is named after Horse Creek, a tributary which enters Spring Creek at Springvale Homestead. The type area and reference section for the formation are: Type area: From the crossing of Gum Creek on the Springvale-Diamantina Lakes road, about 2 1/2 miles upstream to the junction of a well defined creek coming in from the west, then 1 mile up this creek into a shallow gorge (Pl. 5, Fig. 1). Reference Section: Springvale airstrip at the homestead.

The formation caps the low plateau on which Springvale airstrip lies, and extends south-eastwards to about 5 miles east of the Diamantina River. It extends from near Uka Tank north-eastwards for about 28 miles. Outcrop covers approximately 200 square miles.

The Horse Creek Formation consists mainly of brown and grey richly fossiliferous limestone, which contains little clastic material, is very fine-grained, consisting essentially of chemically precipitated calcium carbonate. Partial recrystallization of the material gives a characteristic appearance to the rock in thin section, of darker areas of the original fine carbonate irregularly mottled by clear crystalline calcite mosaic (Pl. G, Fig. 1). Shelly material is commonly infilled with recrystallized calcite and some is veined by calcite mosaics. Finely divided carbonate crops out in a belt up to 30 feet thick along a scarp capped by solid limestone, about 5 miles north-west of Hunter's Gorge. In the type area (S124) a two-foot-thick bed of yellow-brown charophyte-bearing fine-grained argillaceous limestone crops out (Pl. 5, Fig. 1); elsewhere the limestone contains only trace amounts of interstitial argillaceous material and is poorly stratified, whereas bedding is well developed in the argillaceous limestone.

Faecal limestone occurs near the base of the sequence along the western margin of the outcrop. It consists almost entirely of small rod-shaped faecal bodies of fine-grained argillaceous limestone set in a limestone matrix (Pl. 6, Fig. 2). Ostracodes are common in this limestone and their shells are commonly filled with the faecal material. The localization of up to 10 feet of this material along the entire western margin, but not in the east, suggests that the faecal material was concentrated by wave or current action. Except along the eastern margin, a distinctive marker band of green clay, commonly not more than a foot thick and containing rare ostracodes, is invariably present in the base of the Horse Creek Formation. The band grades upwards and is partly brecciated into the overlying limestone of the formation.

The belt of faecal limestone has undergone an unusual silicification. At the top of the sequence is unaltered limestone; below this, the pellets, but not the calcite matrix, have been silicified. Near the base, the lime matrix is leached away to produce a porous, light-weight, white rock, composed largely of silica. It closely resembles tripoli (Pettijohn, 1957, p.433). Ostracodes are silicified and their shell structure preserved. The form of the faecal pellets is preserved, and is responsible for the coarse texture of the rock, which otherwise has the general appearance of diatomite. Analysis, by the Queensland Government Chemical Laboratory, of one specimen of this material from the Springvale airstrip gave the following results (Analysis 1570/59 G.S.):

	Percent
Loss on ignition	13.7
Silica (SiO_2)	62.0
Alumina (Al_2O_3)	11.5
Ferric oxide (Fe_2O_3)	0.6
Calcium oxide (CaO)	9.2
Magnesia (MgO)	2.2
	99.2

This silicification is unusual, for, with all other observed Cainozoic silicification in Western Queensland, the degree of silicification decreased downwards from a surface (presumed to be at or near the surface of weathering). In this case particular beds near the base of the succession were silicified and the silicification increased with depth to the limit of the faecal lithology. The tripoli-type rock was not observed in any other Cainozoic basins in the area.

Some exposed parts of the formation have been silicified to form common opal, with minor veining by chalcedony. The opal in the limestone is honey-brown, whereas that in the green clay is dull green. Ostracode and gastropod shells are preserved in the opal and weather out in profusion on the surface of the rock. Thin laminae of dull to lustrous common opal occur in the leached faecal rock and exhibit an internal undulose structure which in some cases persists into the leached material.

The maximum observed thickness of 40 feet of the Horse Creek sequence is in a scarp on the western side of the Diamantina River, 5 miles north-west of Hunter's Gorge.

MARION BASIN

Sediments of the Marion Basin were deposited within an elongate north-south depression which extended from Windsor Park in the north to beyond the area of investigation in the south. Near Windsor Park it was about 10 miles wide, but it widened rapidly south of Boulia, and was about 40 miles wide at Latitude 24°S. The southern extent is not known, but the Marion Formation has been mapped in the Bedourie, Birdsville, and Betoota 1:250,000 Sheet areas (Reynolds, Olgers, & Jauncey, 1961).

The elongate shape of the outcrop of the Marion Formation, which extends southwards for at least 300 miles, suggests that the formation was deposited in the erosion valleys of a Tertiary drainage system analogous to that of the present Georgina River/Eyre Creek System.

Marion Formation (Casey, 1959)

A sequence of arenaceous sediments - the Marion Formation - was deposited in the Marion Basin. It is named after Marion Downs Station, a grazing property on the Georgina River, 40 miles south-west of Boulia. The type area is in hills 14 miles west of Marion Downs Homestead on the track from Marion Downs to Herbert Downs. A reference section is given 5 miles north-west of Strathelbiss Homestead, 14 miles north of Boulia.

Outcrop occupies two major areas. The northern area, between Windsor Park and Boulia, is separated from the southern, which extends southwards from Marion Downs, by the spread of alluvium at the junction of the Burke and Georgina Rivers. Outcrop in the southern portion is confined between the Mulligan and Georgina Rivers.

The formation has given rise to broad undulating grassy plateaux, which are being deeply dissected by the present cycle of erosion. Dissection is particularly active in the southern outcrop area, where the formation persists only as thin mesa cappings. Mount La Touche, Mount Tobin, The Knob, The Sisters, Mount Tarley, and 12-mile Mountain are all residuals capped by silicified Marion Formation.

The formation consists of quartz sandstone, ranging in grain-size from fine to very coarse, and fine quartz conglomerate. Grains are subangular to subrounded and consist of quartz with rare cream and dark chert; the chert occurs mostly in the coarser fraction. The derivation of the chert fragments from the Palaeozoic and older carbonate rocks to the north supports the hypothesis that the Marion Formation was deposited in a river valley with its source area in the north. Near the base of the sequence, valley fill occurs on a small scale and consists of fragments of the underlying lateritized sandy siltstone. A rough grading is indicated in the formation, the coarser fraction being mostly confined to the basal few feet.

The sequence has been almost completely silicified to form billy, which is described on P 23.

Bedding is poorly developed. Fine and coarse beds are interwedged occasionally in foresets. The formation is sub-horizontal except for the presence of initial dips of up to 20^{o}, which are commonly associated with valley-fill structures close to the base of the sequence.

The Marion Formation unconformably overlies the uneven eroded surface (mottled zone) of the lateritized Lower Cretaceous Wilgunya Formation (Pl. 6, Fig. 2). No junction with other Tertiary formations is exposed; at Windsor Park, where the Noranside Limestone overlies the Marion Formation, the junction is obscured by rubble from the two units. In bores near the Paravituari Waterhole, sandy sediments tentatively regarded as Marion Formation underlie the Austral Downs Limestone (Reynolds, 1960). The maximum observed thickness is 25 feet.

AUSTRAL DOWNS BASIN

The Austral Downs Basin occupied the Upper Georgina River Valley (including Pituri Creek), and except in the extreme south-eastern part, it was confined to the exposed shelf of Lower Palaeozoic carbonate rocks which lies to the north-west of the Great Artesian Basin. It extended from near Herbert Downs into the Northern Territory beyond Urandangi and Linda Downs. Lacustrine limestone, the Austral Downs Limestone, was deposited in the basin.

Austral Downs Limestone (Noakes & Traves, 1954)

This name was given by Noakes & Traves to limestone and chalcedony cropping out on Austral Downs, a property in north-eastern Northern Territory. The type locality is 'The Georgina Valley at Austral Downs and Urandangi'. Whitehouse (1940) recorded the occurrence of chalcedonic limestone along Pituri Creek. The Austral Downs Limestone crops out as elongated areas up to 12 miles wide within the valleys of Georgina River and Pituri Creek. The sequence is better exposed in Pituri Creek. Small areas of similar rocks are exposed on the western side of the Toko Range near Aroota Bore, to the south of Yardida Bore (both in the Northern Territory), and 8 miles north of Craven's Peak.

Outcrop along Pituri Creek, on Herbert Downs, east of the Georgina River on Roxburgh Downs, and in the Jimboola-Carrandotta area, is typified by elongate plateaux. In contrast, at Roxburgh Downs on the western side of the Georgina River, the formation outcrops as scattered small plateaux, ridges, and hills. This topography is clearly an expression of rock type: in the extensive plateau areas, the sequence is chalcedonic and is less eroded than the non-siliceous areas on the west side of the Georgina River at Roxburgh Downs. A typical scarped topography is produced by the dissection of the highly siliceous areas.

The plateaux along Pituri Creek are extensive - the one on which Glenormiston Homestead stands extends along the Creek for about 20 miles, with a maximum width of 3 miles. It is blanketed by a mantle of dark residual soil on which grows Mitchell Grass, but smaller plateaux of the formation are commonly capped by residual siliceous rubble and support only scrubby vegetation. In areas of little dissection, as in the Carrandotta area, the formation underlies extensive dark-soiled Mitchell Grass plains.

The Austral Downs Limestone sequence consists broadly of an upper chalcedonic cap overlying grey, cream, or white limestone, which overlies a zone rich in ferruginous detritus. These three divisions are gradational and one or more of them may be absent from any one outcrop area. The following section from near Pituri Creek, 5 miles north-west of Glenormiston Homestead, is typical for the formation.

Top. 15 feet chalcedony and siliceous limestone, silica content increases towards top of section and white and brown chalcedony weathers out on surface.

5 feet limestone, white, fragmental, with minor chalcedony.

5 feet limestone, impure, white, with some sandy ferruginous detritus.

5 feet ferruginous detritus, calcareous matrix, possibly some spring travertine textures.

Dolomite (Lower Palaeozoic)

Up to 10 feet of the basal part of the sequence is composed mainly of sandy ferruginous detritus derived from the erosion of the laterites. This part of the sequence varies from a sandy, nodular, dense to porous ferruginous rock with calcite veins and intergranular material, to an impure limestone with disseminated rounded ferruginous fragments and quartz grains coated with iron oxide. This rock contains some textures that are similar to those found in modern calcareous spring travertines in the area.

The detritus probably started to accumulate in the Georgina Valley before the lake in which the limestone was deposited had formed. During the lacustrine phase, while the limestone was being deposited, the detritus would have been reworked and redistributed to some extent, and incorporated into the base of the limestone by the precipitation of calcium carbonate in the interstices and by spring travertine. For this reason it was impossible to map the ferruginous detritus and the limestone as separate units.

The ferruginous material grades upwards into cream, grey, and white fine-grained limestone. Where the basal ferruginous layer is absent, the limestone commonly contains fragments of the underlying carbonate bedrock at the base. The limestone is composed of a chemical deposit of fine-grained carbonate, the texture of which is considerably modified by recrystallization. This produces a clotted appearance in thin section, due to an irregular arrangement of areas of dark fine-grained limestone and light crystalline calcite. Breakup of fine carbonate before consolidation, and subsequent cementation of the fragments by later deposited carbonate, produced large areas of limestone conglomerate or breccia up to 20 feet thick. Aggregation of pellets by thin coats of later deposited carbonate is a common feature. The fragmentation is probably due to collapse, caused by the instability of the freshly deposited sediments on an uneven floor of deposition. Pettijohn (1957) regarded such limestone conglomerates (pseudo-breccia) as resulting from the sloughing off of lime from the surface of the lime-depositing plants, e.g. charophytes; but this seems unlikely in the Austral Downs Limestone in view of their size and thickness. The conglomerates are best developed at Roxburgh Downs on the west side of the Georgina River.

The limestone passes upwards into an irregular silicified cap of white and bluish, translucent to opaque chalcedony. This cap seldom exceeds 15 feet in thickness, but at Aroota Bore and Lake Wonditti the whole sequence is silicified. The chalcedony forms massive bands up to 10 feet thick (Pl. 7, Fig. 2), veins, mamillate vug fillings, and irregular masses (Pl. 8, Fig. 1). The massive bands, in some cases, persist laterally and have distinct boundaries. The veins, vug fillings, and irregular masses form a complex reticule pattern within the silicified cap and include numerous residual limestone areas. Limestone textures (clotted, pellet) are commonly preserved in the chalcedony after all other traces of the limestone have disappeared. Traces of iron oxide in the chalcedony stain weathered surfaces brown. The scarps on the west side of Lake Wonditti illustrate this feature. The nature of the silicification and the origin of the silica are discussed on pages 25 and 26.

Apart from the sandy ferruginous base of the formation, clastic grains are rare and consist of subangular to subrounded quartz grains. Dendritic and platy manganese oxides occur in trace amounts in some areas.

Coarsely laminar-nodular limestone occurring as coating up to several inches thick on the surface and in joints of the Palaeozoic carbonates (particularly dolomite) is widely distributed throughout the Georgina Basin and should not be confused with the Austral Downs Limestone. It commonly contains sand and ferruginous detritus, and, rarely, is silicified to chalcedony. It is more widespread than the Austral Downs Limestone and is surface caliche, similar to material figured in Swineford, Leonard, & Fryre (1958).

Non-siliceous sections of the Austral Downs Limestone are poorly bedded (Pl. 8, Fig. 2), but in most areas, this stratification was destroyed by the post-depositional chemical redistribution of calcium carbonate and silica.

The Austral Downs Limestone overlies Lower Palaeozoic dolomitic carbonate rock in all outcrop areas examined. The unconformity is well exposed at a number of localities - the best observed being on the western side of Pituri Creek at Lake Wonditti, Glemormiston, where the siliceous Austral Downs Limestone overlies well jointed dolomite of the Ninmaroo Formation (Pl. 9, Fig. 1). At this locality, botryoidal chalcedony, similar to that of the overlying silicified limestone, fills vugs and the nautiloid fossils in the dolomite immediately below the unconformity.

NORANSIDE BASIN

The narrow Noranside Basin extended for at least 60 miles from Noranside in the north to the Hamilton River in the south. It was separated from another basin which developed within the upper Burke River Valley by a ridge of Cambro-Ordovician carbonate rocks at Digby Peaks. A smaller basin developed on Burnham Station about 16 miles east-north-east of Digby Peaks.

The Noranside Basin lay across the boundary of the Cretaceous sediments of the Great Artesian Basin and the Lower Palaeozoic carbonate rocks of the Black Mountain ridge. Its northern limit overlapped that of the Marion Basin, but the two basins existed at different times. The Springvale Basin is on the southern extension of its trend, but there is no evidence that the two were ever connected. The Noranside Limestone sequence, similar to the Austral Downs Limestone, was deposited in the basin.

Noranside Limestone (Casey, 1959)

The Noranside Limestone is named after Noranside Out-station, which is situated between the Burke River and Wills Creek, 50 miles north-north-east of Boulia. Casey (1959) described the two reference areas for the formation. They were described in detail in Casey et al. (1960) and are here repeated: (1) White siliceous limestone in a gully crossing the Boulia-Selwyn road 1.2 miles south of Old Noranside Well at Latitude 22°12' south, Longitude 140°04' east; (2) Pink, red, and white banded impure limestone at 6-Mile Creek, 1.4 miles south-south-east of 6-mile Bore (Corrie Downs) on Fort William Station and 0.4 miles south of an east-west dog-proof fence at Latitude 22°27' south, Longitude 140°12' east. Chalcedonic limestone was first noted in the Boulia area by Dunstan (1920). Whitehouse (1940) described silicified Late Tertiary limestone from Warenda and Fort William and a summary of this is given in Connah (1958).

Outcrop occurs in a belt 5 to 15 miles wide and in contrast to the Austral Downs Limestone exposure is poor, particularly in the south, where the formation is covered by an extensive plain of alluvium and black soil. Plates of limestone are widely scattered over the surface of the plain.

The sequence is similar to that of the Austral Downs Limestone. Redistributed pink and red lateritic detritus is concentrated within the basal 10 feet and the bulk of the sequence consists of white pellety fine-grained chemical limestone with veins and irregular areas of crystalline calcite. Pellets are commonly aggregated by later lime coats. Clastic quartz grains are rare except in areas rich in lateritic detritus. An irregular zone of chalcedony as massive bands, veins, and irregular masses tops the sequence. It passes downwards into unaltered limestone. Silicification is commonly differential, calcite mosaics and veins being replaced more readily than the fine-grained precipitated lime.

The lower part of the sequence shows a fine bedding which is commonly disrupted either by desiccation or by the action of organisms. Elsewhere the deposit appears poorly stratified.

The Noranside Limestone overlies the lower Palaeozoic and Cretaceous rocks of the area and is covered in part by two ages of alluvium - the younger being that of the present river system. It apparently overlies the Marion Formation at Windsor Park. The greatest thickness observed was 45 feet at reference area (1).

SINTERS

Siliceous sinters crop out at Mount Coley, Mount Whelan, Sugarloaf Hill, and near Boulia on Alderley and Stockport Stations (Fig. 2). These are collectively known as the Mount Coley Sinter (Casey, 1959), although there is no suggestion that they ever existed as a continuous deposit. Sinter forms sharp hills and low rises and overlies unconformably the lateritized Lower Cretaceous Wilgunya Formation.

The sequence consists of brown and white cellular opaline sinter, commonly with ferruginous inclusions (derived from the erosion of the laterites), and milky blue and white chalcedony. No bedding is evident, but massive white chalcedony, when preserved, overlies the sinter.

The sinters are thought to have been deposited in small depressions from siliceous spring waters derived from a fractured aquiclude (Wilgunya Formation) of the Great Artesian Basin. Faulting occurs below the sinter in the Wilgunya Formation at Mount Whelan. Estimated thicknesses for the 'formation' are Mount Coley 120 feet, Sugarloaf Hill 60 feet, and Mount Whelan 35 feet.

PALAEONTOLOGY AND ENVIRONMENT

Springvale Formation

Up to 15 feet of silicified probable algal limestone with rare residual limestone areas crops out as discontinuous arcuate ridges to the west and south-west of Springvale Homestead along the Black Mountain structural line and as expanses of rubble between there and Gum Creek (Fig 3). Most of the ridges have steep westerly slopes and dip at a low angle to the east, probably as a result of post-depositional movement, or possibly because the algal limestones were small bioherms. Outcrop is rubbly because the algal mass has broken up into colonies, concentrically layered and ranging in shape from simple sub-spherical forms to complex irregular bodies (Pl. 9, Fig. 2). Commonly growth is elongate in one direction with small outgrowths in which the layered structure persists.

Partly silicified algal limestone crops out in hills on the north side of the road from Springvale to Diamantina Lakes about 10 miles from Springvale Homestead (S120). This material consists of alternating concentric layers of dark and light grey sandy limestone (Pl. 10, Fig. 1). The light grey bands are of 'spongy' limestone, made dense by later calcite and silica infilling and replacement. The dark grey bands are finer-grained and grade outwards into the spongy mass. Silicification is more intense in the fine bands, which weather out as ribs on exposed surfaces.

Recrystallization has, in most cases, destroyed the structure of the individual algae; however, rare filaments and solid spherical bodies were observed in thin section. Filaments are fragmentary, simple and unbranched, ranging in diameter from 30 to 50 microns. Crosswalls were observed only rarely. The filaments are filled by calcite mosaic. The spherical bodies are solid and composed of uncleaved calcite. They range in diameter from 12 to 32 microns, with most towards the upper limit of the range. The nature of these bodies of organic appearance is unknown; they may be unusual calcite infillings of unicellular algae.

Thin-shelled, plane-spired gastropods occur in chert (silicified limestone) and limestone about 12 miles south of Springvale Homestead (S108). Other thin-shelled fragmentary molluscan remains occur in grey limestone below the Horse Creek Formation about 16 miles south-south-east of the homestead (S145).

The presence of massive calcareous algal deposits in the Springvale Formation suggests that it was deposited in fresh or brackish water. Bradley (1929) described a similar, but much larger, sequence of algal deposits, limestone, and clays from the basal 700 feet of the lacustrine Tertiary Green River Formation from the western United States of America.

Horse Creek Formation

The Horse Creek Formation is by far the most fossiliferous of the Tertiary lake deposits in western Queensland and the one in which the lacustrine origin is most obvious. Fossils include ostracodes, gastropods, charophytes, and probable faecal pellets.

Smooth-shelled ostracodes are the commonest fossils and occur in profusion throughout the sequence. They can be collected from most outcrop areas, particularly in the upper silicified levels, where they weather out on the surface of the plates of common opal. Apparently only one form is present.

Gastropods occur in siliceous limestone rubble near the eastern edge of the Springvale plateau on the west side of Gum Creek, 16 miles south-east of Springvale Homestead and 5 miles north-east of Merrion Downs Bore (S123). Two forms occur, a low spiralled form up to three-quarters of an inch in diameter and a small thin-shelled turreted form up to a quarter of an inch long. Charophyte gyrogonites (female fruiting bodies) are very abundant in a fine-grained creamy brown argillaceous limestone in the type area near Gum Creek (S124). Leaching has removed the gyrogonites, leaving moulds which preserve the characteristic spiral structure. No stems or other parts of the plant were observed. Faecal pellets are concentrated in vast numbers along the western margin of the formation. Excellent exposures occur on the east side of Spring Creek below the Springvale Airstrip. They consist of calcareous-argillaceous material and are preserved in limestone, which is largely silicified and leached. Partly silicified pellets were separated from the calcareous matrix by slow leaching in dilute acetic acid.

The pellets are fragmentary, straight rod-shaped bodies, 1 to 1 1/2 mm. long and about 1/2 mm. in diameter (Pl. 10, Fig. 2). They have a well-defined longitudinal groove, and some have a corresponding flattening or shallow groove on the opposite side. The outer surface of some of the pellets is ornamented with an indistinct low-angle spiral.

The parent organism for this materal was not found, and was presumable soft-bodied. Ostracode shells filled with faecal material are found, but seem too small to be the origin of the faeces.

Marion Formation

The only fossil collected from the Marion Formation is rare though widespread silicified wood. Smaller specimens may have been redistributed from the Cretaceous sediments of the area, but concentrations of large pieces are almost certainly first-cycle. Carter (1959) examined two probable first-cycle specimens from 6-Mile Bore on Strathelbiss Station, 9 miles north-north-east of Boulia, and identified the following:-

1. Mesembrioxylon - Podocarp or possibly non-resinous Cupressinoxylon

2. Cupressinoxylon - very similar to Arthrotaxis.

These fossils give no indication of environment of deposition; however, sedimentary structures in the formation, discussed previously, suggest that it was lacustrine or fluviatile.

Austral Downs Limestone

Although the Austral Downs and similar limestones are widespread in western Queensland, fossil remains in them are rare, probably because forms have been destroyed by calcite recrystallization and subsequent silicification. Whitehouse (1940) regarded these limestones as unfossiliferous, and stated that they were probably surface soil limestones formed between two periods of lateritization. Fossils indicative of a lacustrine origin have now been found in three limestones, and it seems likely that other occurrences referred to by Whitehouse will also be found to be fossiliferous after detailed thin-section examination.

Fossils from the Austral Downs Limestone include charophyte and other algal remains, plant tissue, ostracodes, and foraminifera. Charophyte stems and fruiting bodies (gyrogonites) and rare ostracodes occur in limestone at the Carrandotta Homestead Tank, about 48 miles north-west of Roxburgh Downs on the eastern side of the Georgina River. The gyrogonites have affinities with those of the modern genus Chara (P.R. Evans, pers. comm.).

The siliceous limestones near Aroota Bore on the west side of the Toko Range in the Northern Territory contain probable charophyte stems (Pl. 11, Fig. 1) and fragmentary, simple, unthickened cellular plant tissue (all observed in thin section only). The fossils are from near the base of this sequence, which contains much redistributed ferruginous lateritic material. Tertiary charophyte fructifications and stem structure are illustrated in Horn of Rantzien (1959).

Foraminifera were collected from only one locality. Abundant well preserved forms associated with rare ostracodes occur at the top of a small plateau at the junction of Manner Creek with the Georgina River on Roxburgh Downs; the host rock is a hard manganiferous breccia. The foraminifera could be examined only in thin section (Pl. 11, Fig. 2). Rotaline and globigerine forms were present, but specific identification and age determination were impossible (Dr Irene Crespin, pers. comm.).

The foraminifera may be remanie fossils; but the only possible marine source rocks from which they could be derived are the Lower Cretaceous clays of the Great Artesian Basin, in which globigerine and rotaline forms occur. These clays were deeply lateritized before the deposition of the Austral Downs Limestone, and hence the derivation of fresh calcareous tests from them is considered unlikely. They are believed, therefore, to have lived within the

the environment of deposition of the limestone. Glaessner (1945) indicated that foraminifera, including rotaline and doubtful globigerine forms, occur in continental brackish environments. Ludbrook (1953) reported abundant rotaline forms associated with ostracodes and charophytes from Sub-Recent sediments in Lake Eyre in South Australia.

Modern charophytes are small, aquatic plants which live entirely submerged in clear, quiet or slowly moving bodies of water. They inhabit fresh or brackish water, but one species shows tolerance to high salinity (18 parts per thousand chloride in the Baltic Sea). Charophytes have wide tolerance to lime concentration, but pH is the controlling factor, most charophytes being confined to alkaline water. Some, however, grow in acidic water, while others exist in fluctuating acid-alkaline water (Peck, 1957).

Hence the association of charophytes, foraminifera, and ostracodes suggests a brackish continental lacustrine environment for the deposition of the Austral Downs Limestone. The low percentage of clastic material in the Austral Downs Limestone, except in the derived lateritic detritus at the base, suggests that it was formed during a period of low rainfall. This was also suggested by Whitehouse (1940) and Noakes et al. (1959). It is thought that water for the lake or lakes was derived initially from springs rather than from rainfall, which is supported by the presence of probable spring travertine textures within the basal detrital zone. These textures probably reflect spring action during an early phase of the rising watertable as the lakes were forming.

Noranside Limestone

Fossils include ostracodes, plant tissue, gastropods, diatoms, and possibly other algae. Ostracodes do not weather out on the surface of the rock and were observed only in thin sections of rocks from near Noranside Homestead.

Thin-shelled turretted gastropods, plant tissue, and diatoms are common in limestone containing ferruginous detritus along 6-Mile Creek near the Fort William/Corrie Downs boundary. The best exposure is at a fence corner, 1.4 miles west of 6-Mile Bore on Corrie Downs. Forms identified from this locality are (Dr Crespin, pers. comm.);

gastropod	:	?Bulinella sp.
diatoms	:	Diploneis cf. elliptica
		Epithema sp.
		Navicula sp.

The diatoms present are identical with those from deposits at Innot Hot Springs in north Queensland, at South Yarra in Victoria, at 8-Mile Creek in South Australia, and in various spring and lake deposits in south-west Western Australia (Crespin, 1947).

A similar environment of deposition to that of the Austral Downs Limestone is postulated for the Noranside Limestone.

AGE AND RELATIONSHIPS

The suggested relationships of the formations to one another based on all available information is set out in the table on page 20. The role of lateritization and palaeontology in these determinations is discussed below.

DIAGRAMMATIC RELATIONSHIPS OF TERTIARY FORMATIONS

	Springvale Basin	Marion Basin	Austral Downs Basin	Noranside Basin
Post-Laterite	Horse Creek Formation		Austral Downs Limestone	Noranside Limestone
		Marion Formation		
Laterite	Springvale Formation			
Bedrock	?Lower Tertiary, Upper and Lower Cretaceous	Lower Cretaceous	Lower Palaeozoic Carbonates	Lower Cretaceous and Lower Palaeozoic Carbonates

Various ages have been assigned to lateritization in Australia. For example, Bryan & Jones (1946) regarded the period of laterite formation as Miocene, whereas Whitehouse (1940) deduced two periods of lateritization during the Pliocene.

It has been suggested also that lateritization is still active in some parts of Australia or has recently been so, though on a less intense scale.

Lateritization was certainly active in Australia during these times. However, I believe that the formation of laterite profiles (i.e. the preservation in situ of the products of chemical deep weathering) is controlled, in any one area during an overall time of lateritization, by the stability or instability of the surface exposed to weathering at that time: gentle regional earth movements during a time of lateritization would be expected to upset the surface stability, resulting in the erosion of the developing laterite profiles, while laterite continues to form in adjacent regions. Thus, the time limits of the formation of lateritic profiles may change from region to region and caution must be exercised in using the laterites as agents of correlation. Hence, it is contended that:

(a) The products of lateritization can be used satisfactorily only in local correlation. The table (Diagrammatic Relationships of Tertiary Formations) is based partly on this principle.

(b) The products of lateritization can be used in giving relationship to the time scale only when the limits of lateritization can be locally established. For example, Condon (1954) was able to show, by the study of lateritized marine sediments of known age, that in the Carnarvon Basin of Western Australia lateritization took place from the Eocene to the late Miocene or possibly Pliocene.

There is no evidence to establish the local age limits of lateritization in this area of western Queensland, and so laterite cannot be used to date the post-Cretaceous sediments here.

Fossils are not plentiful and the taxonomy and range of those that do occur are imperfectly known; but such fossil evidence as is available has been used in estimation of age.

The Springvale Formation is probably the oldest of the Tertiary Formations here described. It overlies Wilgunya Formation (Aptian and Albian), the Winton Formation, regarded as Cenomanian or younger by Whitehouse (1954), and, in the Goyder Range, the Moses Sandstone of probable Lower Tertiary age (W. Jauncey, pers. comm.).

On the grounds of position, type of deposit, and lithology, the Austral Downs and Noranside Limestones are regarded as equivalents. The Noranside Limestone overlies the Marion Formation on Windsor Park. Diatoms from the Noranside Limestone are late Tertiary or early Quaternary (Dr Irene Crespin, pers. comm.), and charophytes from the Austral Downs Limestone have modern affinities. On this basis, it is suggested that these limestones are late Tertiary or early Quaternary in age.

There is no direct evidence for the age of the Horse Creek Formation. It unconformably overlies the Springvale Formation, and may be the time equivalent of the Noranside Limestone (tectonically related). A late Tertiary or early Quaternary age is suggested.

The Mount Coley sinter overlies the eroded laterite profile developed on the Lower Cretaceous Wilgunya Formation. As do the Tertiary units of the region, it caps residual hills at elevations of up to about 100 feet above the present general land surface. For these reasons a post-lateritic Tertiary age is presumed for the sinters.

TECTONICS

The post-Cretaceous tectonic history of the area is characterized by broad regional warping, associated with minor movement along the old Burke River Structure. Because of the broad nature of the warping it is difficult to recognise its effects in the field, particularly in the Great Artesian Basin, where exposure is poor.

The Burke River Structure (Pl. 13) is the expression of a tectonic belt which was active at least from the Lower Palaeozoic to the Tertiary. In the Black Mountain area, 35 miles north-east of Boulia, it is a north-north-west-trending graben bounded by the Black Mountain Fault on the west and the Momedah Fault on the east (Casey et al., 1960). In the Springvale area, 80 miles south of Black Mountain, surface faulting in the Cretaceous sediments of the Great Artesian Basin shows the southern extension of the Black Mountain Fault. There is no evidence of faulting along the projected line of the Momedah Fault at Springvale.

It is assumed that the Springvale Basin was initiated by movement related to the Black Mountain Fault. The Springvale Formation, which was the first formation deposited in the basin, is disturbed by minor faulting with a north to north-west trend within the Black Mountain Fault Zone. To the east of the zone minor warping occurred. The Black Mountain Fault Zone was not observed south of Uka Tank (20 miles south of Springvale Homestead) and is apparently truncated here by a marked north-north-easterly fault system associated with minor folding. This north-north-east trend parallels the axes of the post-Cretaceous fold structures of the Innamincka-Betoota Region (Sprigg, 1958), in the south-west portion of the Great Artesian Basin and contrasts with the north to north-north-west trend of the major structures (Burke River, Toko) in the Palaeozoic and older rocks of the Boulia Shelf.

The Horse Creek Formation was deposited after the deformation of the Springvale Formation since it fills synclinal warps and thins over anticlinal areas in the older formation. With the exception of possible tilting on a regional scale, there is no evidence of deformation in the Springvale Basin after the deposition of the Horse Creek Formation.

On the Boulia Shelf the Austral Downs Limestone was deposited in the present valley of the Georgina River, in a lake presumably formed as the result of warping in the Great Artesian Basin to the south. The Noranside Basin, situated across the boundary of the Lower Palaeozoic sediments of the Black Mountain Ridge and the Lower Cretaceous sediments of the Great Artesian Basin, may have been initiated by similar warping or by movement associated with the adjacent Burke River Structure.

After the deposition of the Austral Downs and Noranside Limestones there was a low regional tilt of the Boulia Shelf to the south which presumably initiated the present drainage system. This tilt was an effect of the Selwyn Uplift (Öpik, 1960, p. 93) and is evidenced by the difference in the elevation of the base of the limestone along the length of the deposits: about 130 feet between Tobermory and Glenormiston (70 miles), about 90 feet between Jimboola and Glenormiston (55 miles), and about 200 feet between Noranside and the Hamilton River measured along the length of the Noranside Limestone (60 miles). These figures indicate that the tilt on the Noranside Limestone is greater than that on the Austral Downs Limestone.

SILICIFICATION

The late Tertiary geological history of the Boulia region was marked by intensive silicification of the superficial rocks. The Marion Formation, the Noranside and Austral Downs Limestones, and the siliceous sinters are strongly silicified. Surface silicification of the Horse Creek Formation was less intense, probably because the original limestone contained little silica. Silicification of the Springvale Formation is not of the surface type and probably it was not exposed to weathering after the deposition of the overlying Horse Creek Formation until the present cycle of dissection. The Noranside Limestone overlies the silicified Marion Formation at Windsor Park. However, the contact is completely obscured by rubble and it is impossible to deduce whether two periods of silicification are represented or whether the formations were silicified together to form a single profile.

Silicification of the Marion Formation

The Marion Formation, which consists of poorly stratified quartz sandstone and grit, overlies the mottled zone of the truncated laterite profile which was developed on the Lower Cretaceous Wilgunya Formation. The younger formation is almost completely silicified to form the siliceous rock 'billy', and forms part of the extensive billy sheet of inland Australia which on dissection has given rise to the great gibber plains or stony deserts.

The products of silicification form a distinct profile up to 30 feet thick on the Marion Formation, in which the degree of silicification decreases downwards from the upper levels of the formation to the base. Thus, at the base of the formation, the porous gritty sandstone texture and sedimentary structures are preserved. This basal material grades up into a hard, dense, but in some cases porous, brittle billy in which the nature of the original sediment is destroyed. Corresponding with the upward increase in intensity of silicification, grain size and grain contact decrease towards the top of the profile. In the upper levels of the profile, a pseudo-conglomerate texture is developed, in which apparent pebbles of billy are aggregated in a matrix of the same material. These pseudo-conglomerates, which are not silicified conglomerate of the original sediments, characteristically occur in smooth-surfaced vertical columns up to four feet in height and several feet across (Pl. 12, Fig. 1).

The lithology of the billy depends upon the intensity of silicification and hence varies from the base to the top of the profile. At the base, where sedimentary textures are preserved, the rock may be bonded by layering of siliceous and/or ferruginous cements that fill the intergranular spaces, and the rock differs little in general appearance from the original sediment. Elsewhere in the profile, open-space filling by cements is rare and the rock consists essentially of poorly sorted chemically corroded quartz and other siliceous grains set in a groundmass of amorphous silica. The corroded grains present deeply embayed to sharply angled outlines and commonly the boundary between grain and matrix is gradational. Grain contact is low and the matrix commonly exceeds 30 percent of the total rock. The matrix consists of chalcedonic or opaline silica or forms intermediate in properties between the two; intermediate forms observed exhibit the spherulitic interference pattern of chalcedony with the low refractive index of common opal. The colour of the billy ranges from grey to honey-brown or red-brown and depends upon the quantity of iron oxide in the matrix.

The silicification of the Marion Formation is a post-depositional feature, since normal sedimentary structures and textures are commonly preserved below the gradational profile of silicification developed on it. In the absence of any evidence of an outside source of silica, the corrosion of the siliceous grains of the formation within the silicified profile indicates that the silica of the matrix of the billy was derived from the constituent grains themselves. It follows that the silicification involved the chemical transformation of the siliceous grains of the parent rock to opaline or chalcedonic silica. This transformation is regarded as the key to the formation of billy on siliceous rocks.

The quartz grains in the rock in the higher parts of the billy profile are placed with complete irregularity in the siliceous matrix, and the rock texture bears little or no relationship to that of the original sandstone (Pl. 12, Fig. 2). Fragments of the same grain when cut by silicification rarely have the same optical orientation, and corroded surfaces of different grains lie in close proximity, occupying less space than they would have required in the original sandstone framework before they were corroded and reduced in size. The grains have therefore moved during silicification, and because grain fracture is rare, a gel phase allowing this movement was probably involved. Such a phase would allow for any change in volume that might take place in the transformation of the quartz grains of the original sandstone to the amorphous silica of the billy matrix. The columnar jointing producing the billy columns at the top of the profile may have resulted from tension caused by the drying out of the gel phase.

The basal portion of the Marion Formation commonly contains granular iron oxide or is iron-stained. The iron oxide is thought to be of detrital origin and derived from the erosion of the laterite profile developed on the Wilgunya Formation, on part of which the Marion Formation was deposited. The iron oxide has been concentrated to a minor degree during the silicification, and is the source of the brown colour of the billy in some areas. Movement of silica and iron oxide during silicification is further evidenced by the presence of opaline fracture-fillings impregnated with iron oxide in the Wilgunya Formation immediately below the silicified Marion Formation at 12-Mile Mountain. Wherever, between Windsor Park and the southern limit of the area under discussion (Pl. 13), the base of the Marion Formation was observed, it unconformably overlies the dissected laterite profile (mottled zone) developed on the Cretaceous sediments of the Great Artesian Basin. The same sort of clear break between the lateritization and the billy formation, with erosion and the deposition of sediments intervening, was noted by Jessup (1960) in the south-eastern portion of the Australian arid zone. Elsewhere, authors - for example Condon (1954), Wopfner (1960), and Whitehouse (1940) - have regarded the billy as a siliceous zone within the laterite profiles. It may be significant that, in the examples illustrated by Condon and Wopfner, the billy zone, when present, was at the top of the lateritic profile. Detailed investigation is required to assess the full significance of the break between the development of the laterite profiles and the formation of the billy crust in the Boulia region and elsewhere. Silicification to form billy was not confined in the Boulia region to the Marion Formation; billy formed on quartzose sediments of the Lower Cretaceous Longsight Sandstone at Mount Ninmaroo, on Ordovician sandstone in the Toko Range, and on ?Permian fluvio-glacials near Aroota Bore, Tobermory. From this it is concluded that silicification to form a billy profile is the result of chemical weathering of all exposed quartzose rocks in response to a particular suite of climatic conditions. As both weathering products are so commonly associated the billy profiles possibly owe their origin to climatic conditions closely related to those causing lateritization.

Silicification of the Austral Downs and Noranside Limestones

The Austral Downs and Noranside Limestones characteristically have a chalcedonic cap (Pl. 7, Fig. 2; Pl. 8, Fig. 1). The presence of residual limestone and limestone structures within the cap, as described on page 14, indicates that the limestone has been silicified, and that the siliceous cap is not a depositional feature. The profile of silicification is analagous to the billy profile imposed on the Marion Formation in that the degree of silicification decreases downwards from the top of the sequence. There is no obvious outside source for the silica, and it must be concluded that the silicification involved the concentration of the silica from the originally siliceous limestone into the upper levels of the sequence. The absence of a siliceous cap on the Austral Downs Limestone in some areas may be due to low silica content in the original limestone in those parts. Silicification was probably in response to the same type of weathering environment that caused the silicification of the Marion Formation; however, there is no positive evidence to show whether or not the two units were silicified comtemporaneously. Whitehouse (1940) regarded the silicification of the limestone as indicative of a second period of lateritization in the area.

The presence of large quantities of silica within the original limestone presents many problems because calcium carbonate and silica are soluble at different pH values. It is possible that silica was extracted from solution by siliceous organisms such as diatoms or sponges: but diatoms in the limestone are rare, and siliceous sponges are unknown. On the other hand, these organisms, if originally present, would tend to be destroyed along with calcareous fossils during the post-depositional redistribution of silica and calcium carbonate.

Australian distribution of siliceous limestone

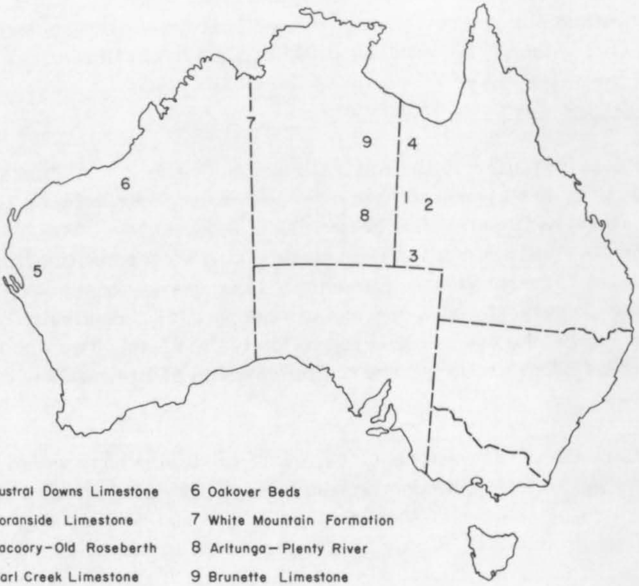
Limestones similar to the Austral Downs and Noranside Limestones are widely distributed in Australia. In Queensland, numerous outcrops occur between Boulia and Birdsville, the best known being at Cacoory and Old Roseberth (Whitehouse, 1940). Reynolds, Olgers, & Jauncey (1961) show the position of all known outcrops of chalcedonic limestone in this region. Their use of the term 'Austral Downs Limestone' for these is considered inadvisable since there is no evidence to suggest that there was ever depositional continuity between them and the Austral Downs Limestone several hundred miles to the north. Two small previously unrecorded outcrop areas occur about one and ten miles south of Breadalbane Homestead on the Boulia-Bedourie road.

The Carl Creek Limestone (Jack, 1896), at Riversleigh in north-west Queensland, was deposited in an area of Cambrian Limestone in the Gregory River Valley. It consists of lacustrine or spring limestone with abundant fossil bones and gastropods. Since the deposit overlies lateritic detrital material, it may be of similar type to the Austral Downs and Noranside Limestones, but it lacks the characteristic silicification. The Carl Creek Limestone is described by Whitehouse (1940) and has been referred to by Daintree (1872), Jack (1896), Cameron (1901), Ball (1911), David (1914), Dunstan (1920), Connah (1958), Paten (1960), and Carter, Brooks, & Walker (1961). Noakes & Traves (1954) described it under the name 'Verdon Limestone'.

Konecki, Dickins, & Quinlan (1958) described chalcedonic limestone from the Wooramel River region of Western Australia. The sequence is 30 feet thick with a thin band of shale and red-stained quartz greywacke at the base. This deposit, which is not closely related to calcareous bedrock, was regarded as a lacustrine deposit related to the last cycle of erosion.

Traves, Casey, & Wells (1956) described the Oakover Beds, a chalcedonic limestone sequence up to 100 feet thick in the Canning Region of Western Australia. A five-foot band of derived lateritic detritus marks the base of the deposit. Basement to the Oakover

Fig.7-DISTRIBUTION OF CHALCEDONIC LIMESTONES IN AUSTRALIA



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Beds includes dolomitic limestone, tillite, and metamorphics. The authors concluded that these beds were a chemical lacustrine deposit formed in the old Oakover River Valley. Casey & Wells (1964) described a similar formation, the Lawford Beds, in the North-eastern Canning Basin.

The White Mountain Formation from the Ord River region of Western Australia (Traves, 1955) consists of up to 370 feet of chert, siltstone, and marl containing gastropods, algae, foraminifera, sponges, ostracodes, and insects. It overlies sandstone basement. Traves thought that the formation was of the same type as the Austral Downs Limestone, but pointed out the significant difference in the high proportion of clastics in the White Mountain Formation.

Madigan (1932) and Smith, Vine, & Woolley (1960) described up to 90 feet of gastropod-bearing chalcedonic limestone, limestone, and rare clastic sediments - the Arltunga Beds - from the Arltunga Plenty River region of the eastern Northern Territory. The deposit contains lateritic detritus at the base or overlies ferruginous laterite in situ. The Arltunga Beds overlie a basement of Archaean gneiss.

Noakes & Traves (1954) described the Brunette Limestone, a chalcedonic limestone similar to the Austral Downs Limestone from the Barkly region of the Northern Territory.

Relationship of the siliceous limestones to lateritization

The Austral Downs and Noranside Limestones overlie carbonate rocks which provide a ready source of carbonate for their deposition. A major area of the Oakover Beds (Traves et al., 1956) also overlies carbonate bedrock, and it is significant that these three deposits are by far the largest of those described. A number of chalcedonic limestones, however, are not related to calcareous bedrock; for example those between Boulia and Birdsville and in the Wooramel River, area which overlie argillaceous sediments, the White Mountain Formation, which overlies sandstone, and the Arltunga Beds, which overlie metamorphics.

In almost every case, irrespective of bedrock, there is a close relationship between the chalcedonic limestone and the laterite; i.e. the limestones overlie ferruginous lateritic detritus, or rest directly on the ferruginous zone of the laterite in situ. This is regarded as the key to the origin of the chalcedonic limestone of this type. A number of authors have noticed this relationship in the past; for example, Konecki et al., (1958), Traves (1955), Noakes & Traves (1954), and Noakes, Carter, & Opik (1959); and have regarded lateritization as the source for the calcium carbonate and silica.

Noakes et al. (1959), when considering the source of silica and carbonate in the Austral Downs Limestone, suggested that 'The calcium carbonate and silica freed by the processes of lateritization were carried into a lake................ and were deposited during a subsequent arid period'. Since the laterite was to some extent dissected before the deposition of the limestone, the persistence of such a lake seems unlikely. On the other hand, ample storage for carbonate and silica released by lateritization is provided by underground water which may be released from springs during a subsequent lacustrine phase.

Hence the lime carbonate and silica released by the lateritization of the country rock provide the source materials in the formation of the chalcedonic limestones. However, where the bedrock is carbonate, the proportion of available carbonate is enormously increased, and so there is a direct relationship between the size of the deposit and the carbonate content of the bedrock.

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M.A. Condon, Assistant Chief Geologist, Dr A.A. Öpik, Supervising Geologist, and the above party members of the Bureau of Mineral Resources, and T.H. Connah, Senior Geologist of the Geological Survey of Queensland, assisted in no small way by their criticism and willingness to discuss the many problems encountered.

The author is grateful to members of the Micropalaeontological Section of the Bureau of Mineral Resources under Dr Crespin, for the examination of some of the palaeontological material collected, and to members of the staff of the Geological Survey of Queensland who assisted in the preparation of numerous thin sections and examination of specimens submitted to the laboratory.

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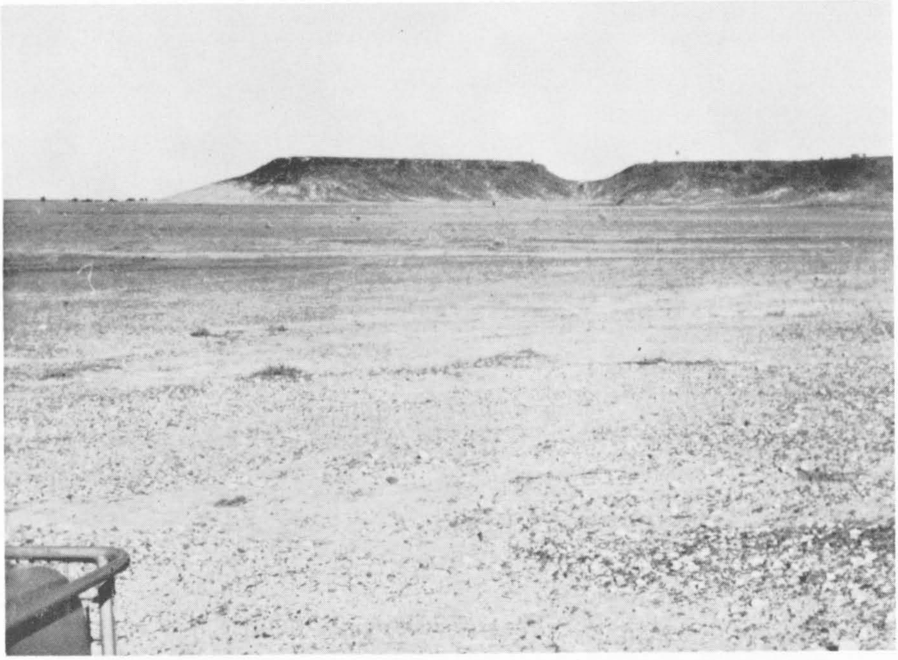


Figure 1.—Dissected ferruginous-capped plateau of the Springvale Formation, 2 miles south-west of Springvale Homestead (type area). (Fig. 7 is a section through the plateau in this area)

Figure 2.—Silicified ?limestone, Springvale Formation. Clotted texture of iron-stained opaline silica, silicified concretion or oolite in centre. (X 56)

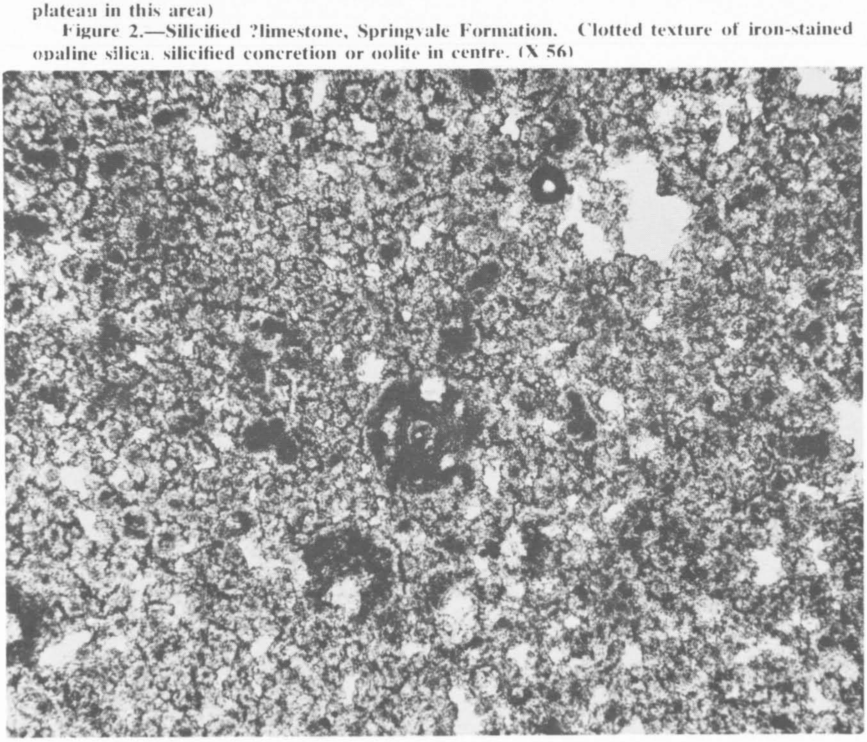


Plate 2

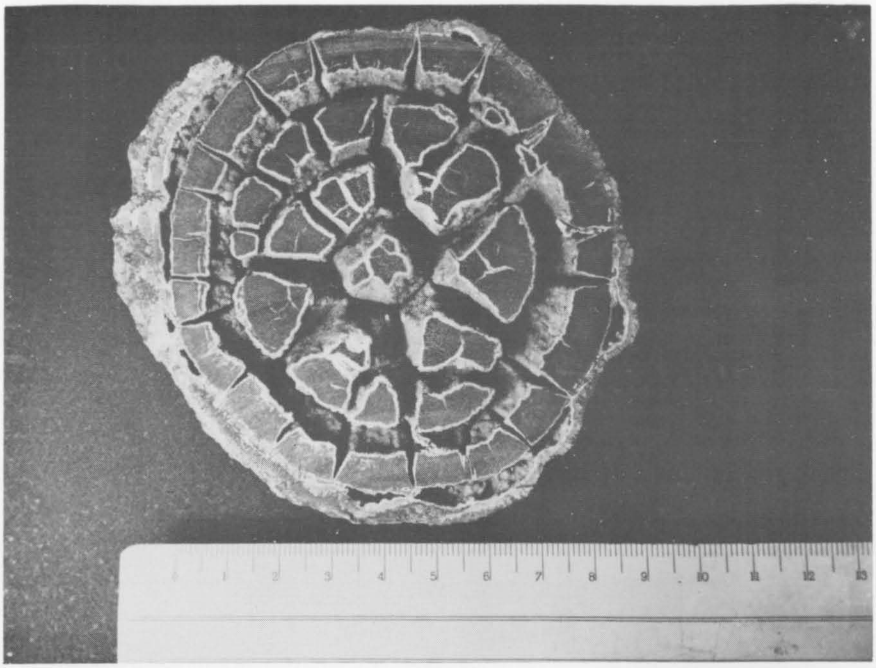
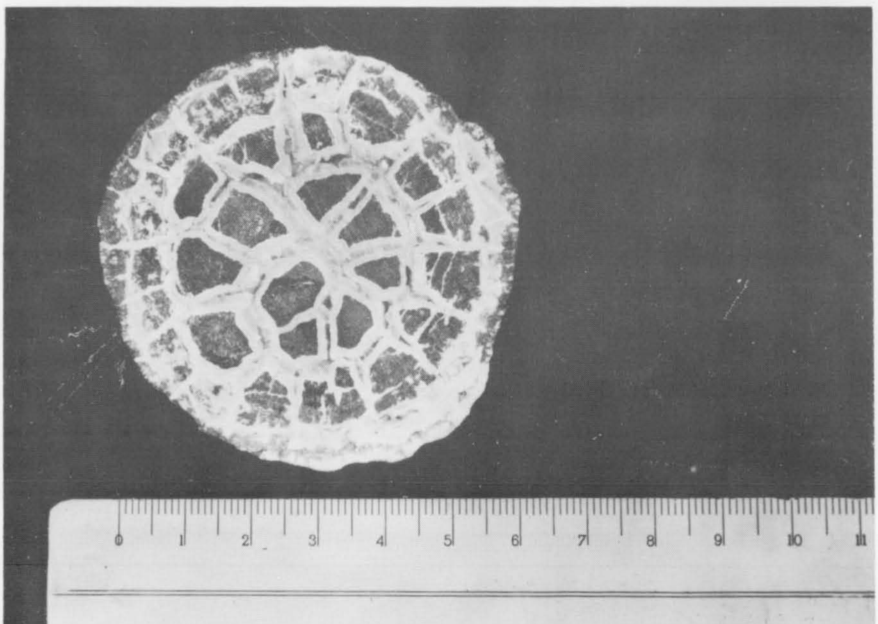


Figure 1.—Section of septarian nodule, Springvale Formation, showing a papery coating of fine quartz crystals coating the syneresis cracks (diameter 9 cm)

Figure 2.—Section of septarian nodule, Springvale Formation, with coarse quartz crystals infilling the syneresis system (diameter 6 cm)



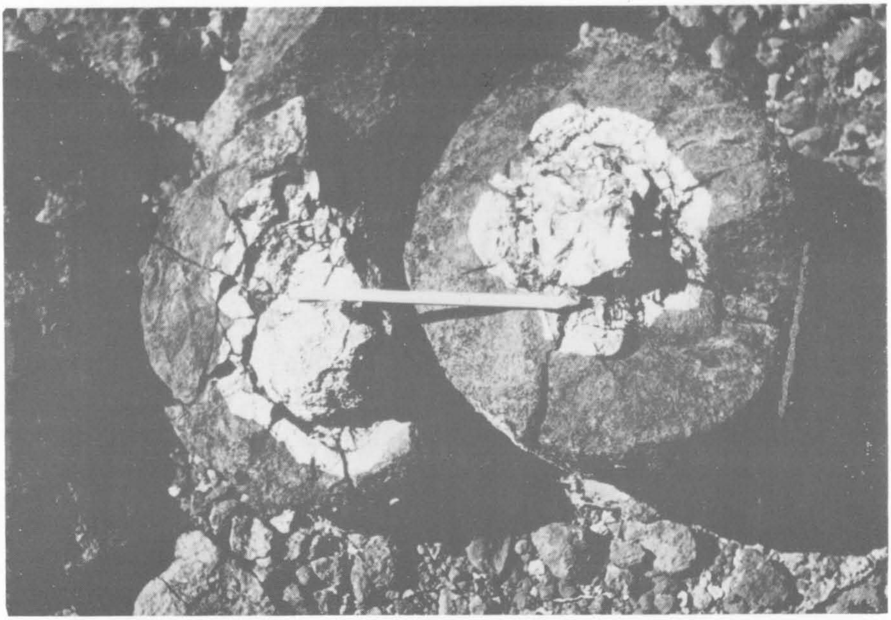
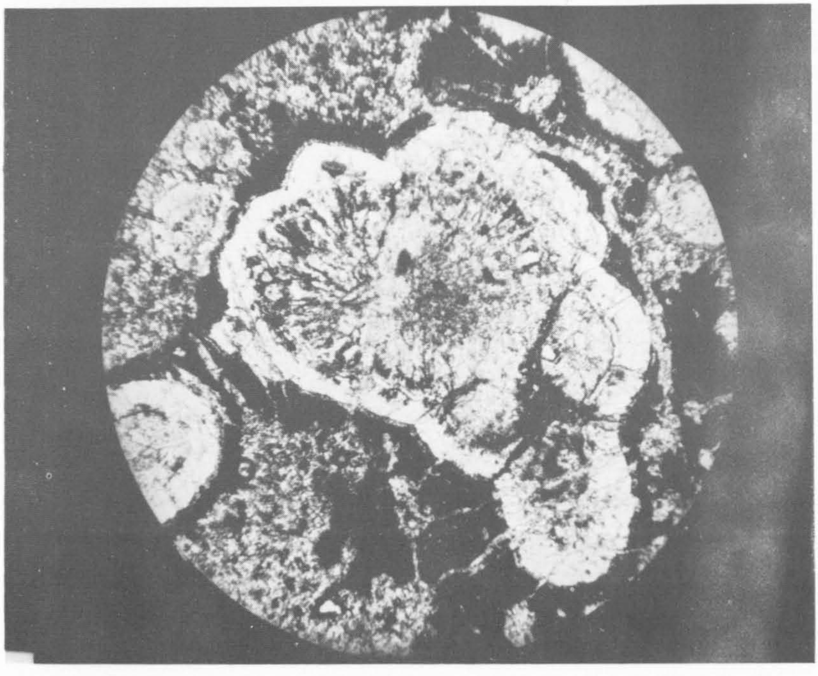


Figure 1.—Ferruginized calcareous concretion, Springvale Formation, showing poorly developed syneresis system. These forms appear to be intermediate in type between solid concretions and septaria

Figure 2.—An example of secondary spherulitic calcite growth in ferruginized limestone from the Springvale Formation. Earlier-formed siliceous concretions (lower right) are cut by the large spherulite (centre). (X 46, plane polarized light)



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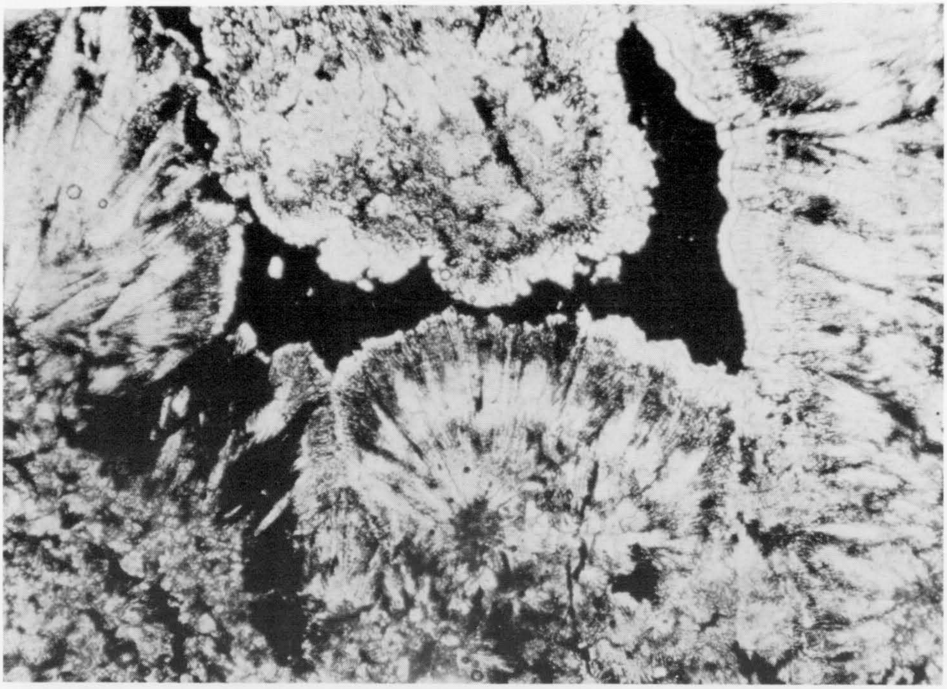
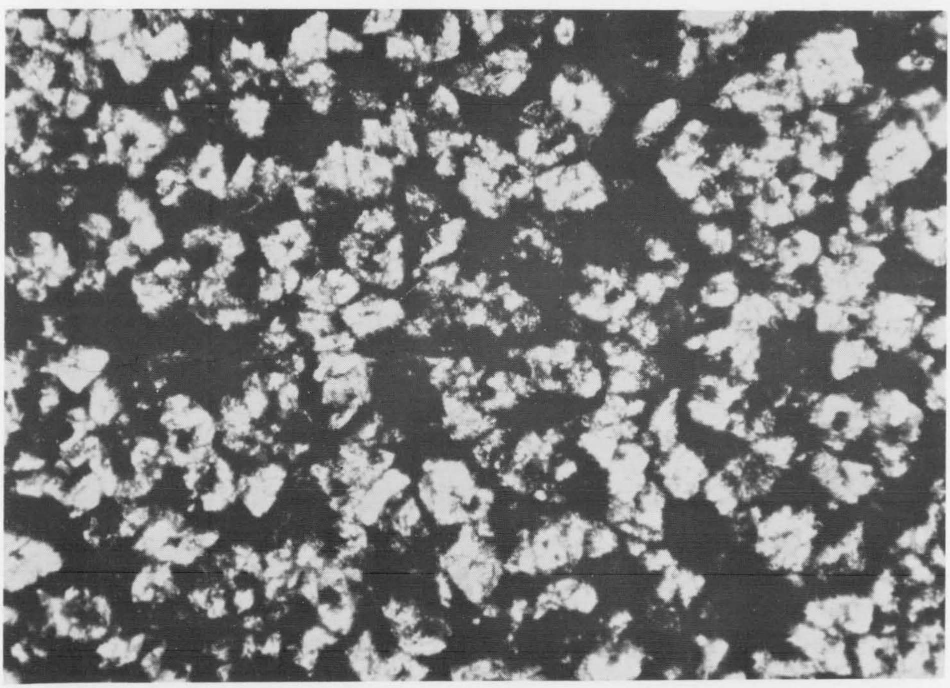


Figure 1.—Later spherultic calcite growth in a ferruginized calcareous concretion from the Springvale Formation. (X 30, plane polarized light)

Figure 2.—Recrystallized ferruginized limestone, Springvale Formation. Iron oxide (dark) mostly confined to intercrystal area (X 105)



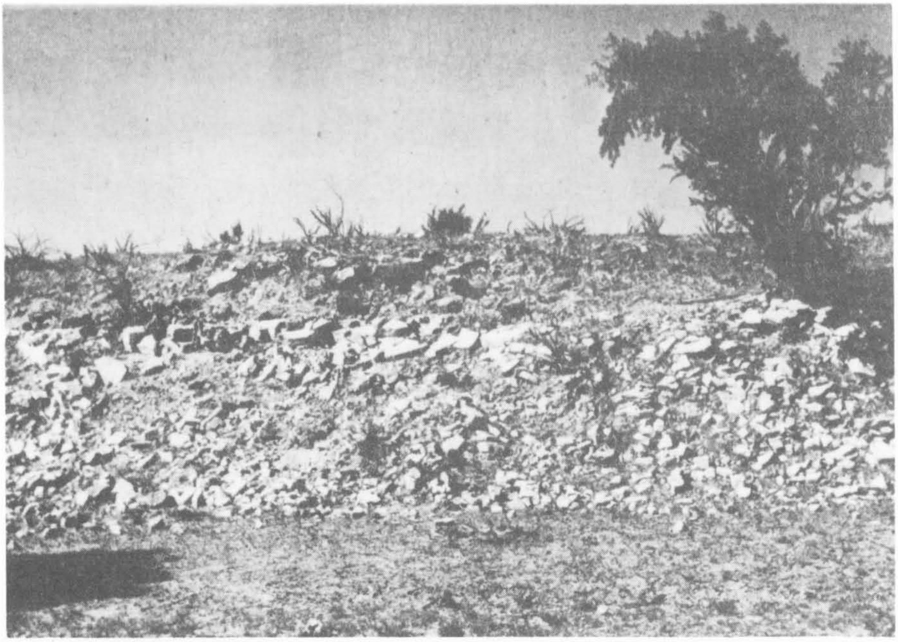


Figure 1.—Type area (S 124) of the Horse Creek Formation showing the thin band of well-bedded argillaceous charophyte limestone (breaking up) in an otherwise poorly stratified limestone section.

Figure 2.—Grey limestone of the Horse Creek Formation overlies ferruginized Springvale Formation in scarp on the west side of the Diamantina River about 5 miles north-west of Hunter's Gorge

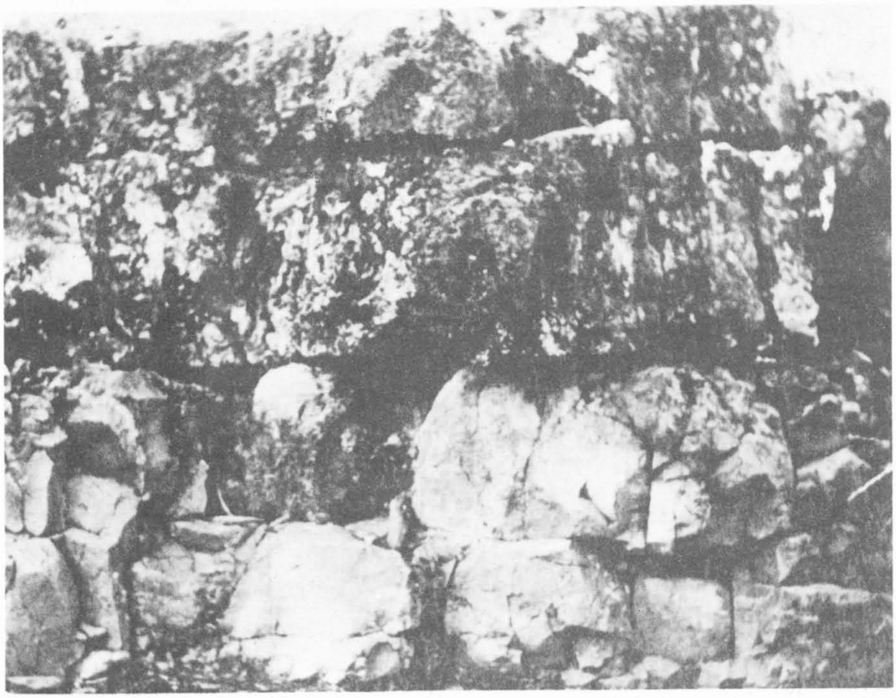


Plate 6

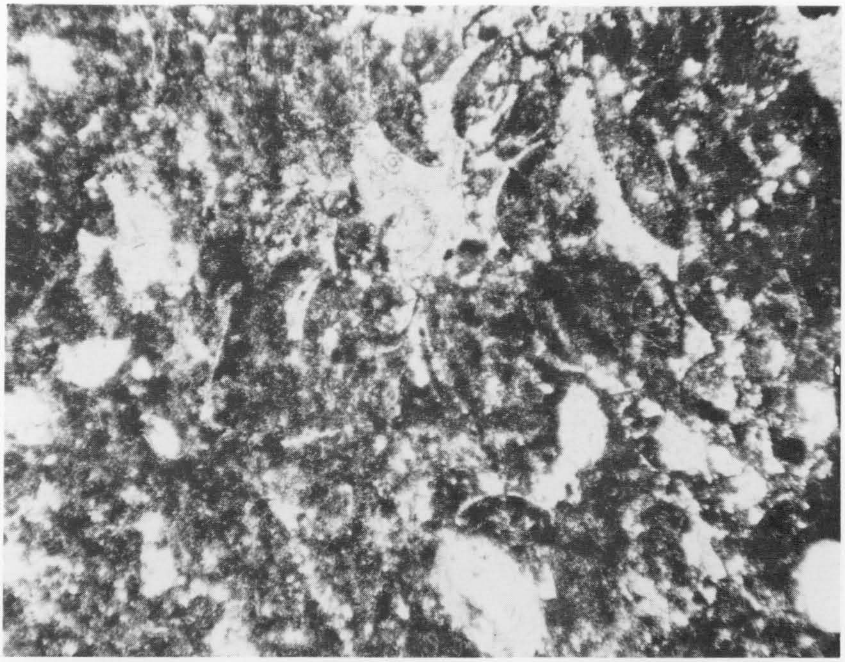
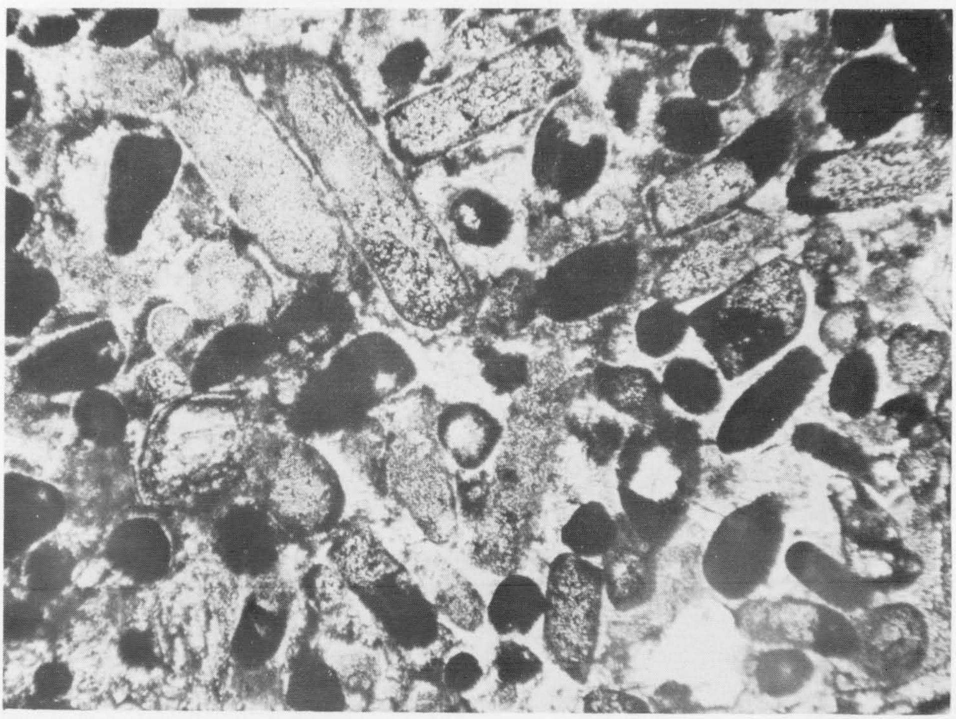


Figure 1.—Lacustrine limestone containing shell remains, Horse Creek Formation. Dark clotted precipitated carbonate with irregular clear recrystallized calcite area. Thin shell fragments are scattered throughout. (X 70)

Figure 2.—Faecal limestone, Horse Creek Formation (X 40)



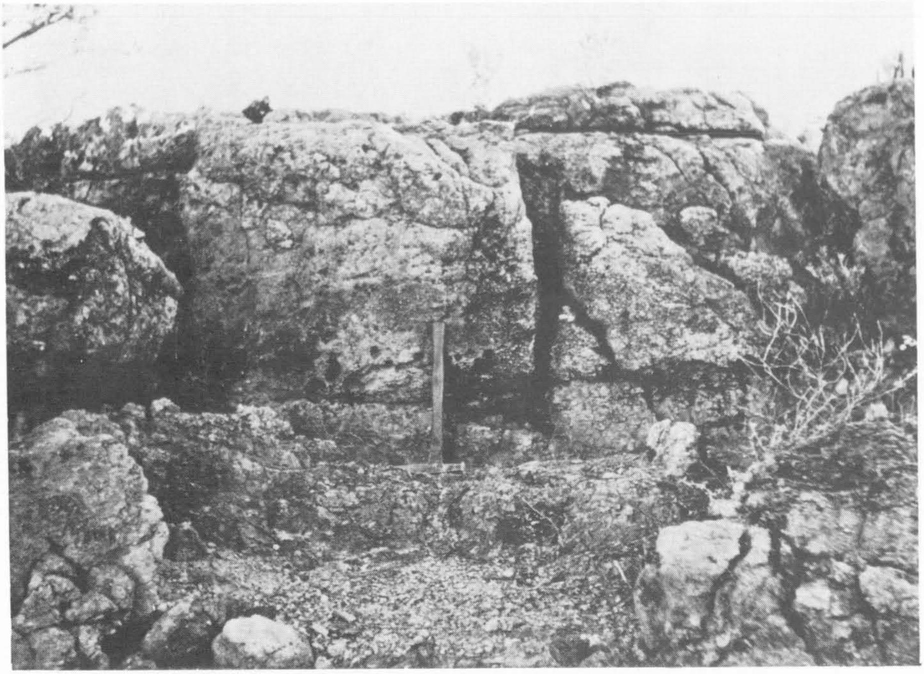


Figure 1.—Partly silicified Marion Formation in blocky outcrop (top) unconformably overlying the finely fractured and indurated lateritized Wilgunya Formation at 12-Mile Mountain

Figure 2.—Austral Downs Limestone, Glenormiston. Massive chalcedony band (central top) overlies partly silicified grey limestone

Figure 1.—Austral Downs Limestone, Glenormiston, showing irregular siliceous replacement of limestone

Figure 2.—Poorly stratified non-siliceous white limestone of the Austral Downs Limestone, Roxburgh Downs

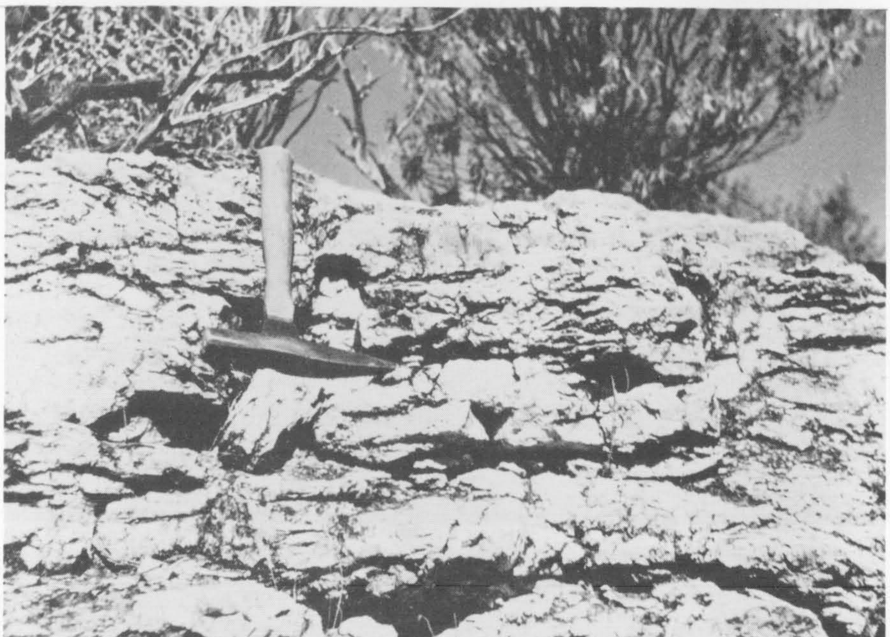


Figure 1.—Silicified Austral Downs Limestone overlies jointed Ordovician dolomite at Lake Wonditti, Glenormiston

Figure 2.—Silicified ?algal colony, Springvale Formation (slightly enlarged)

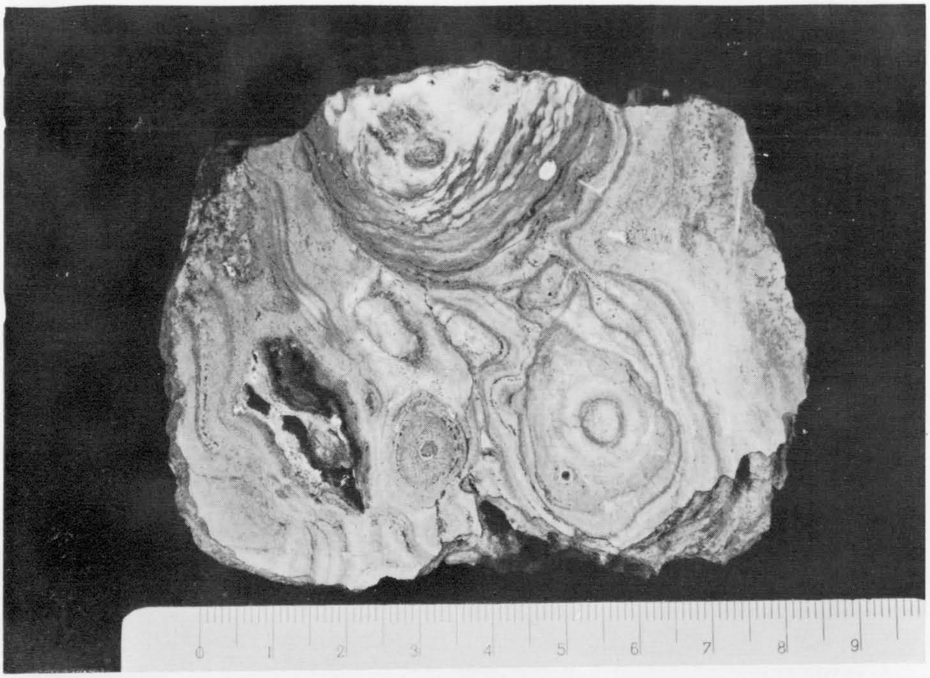


Figure 1.—Algal limestone from locality S 120, Springvale Formation

Figure 2.—Faecal pellets chemically separated from partly silicified faecal limestone of the Horse Creek Formation (X about 10)

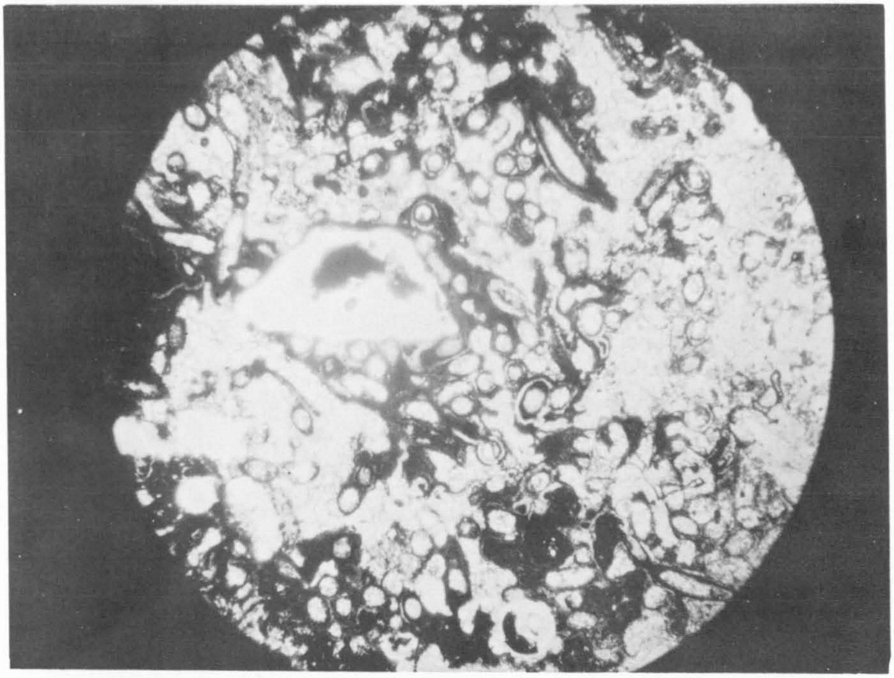
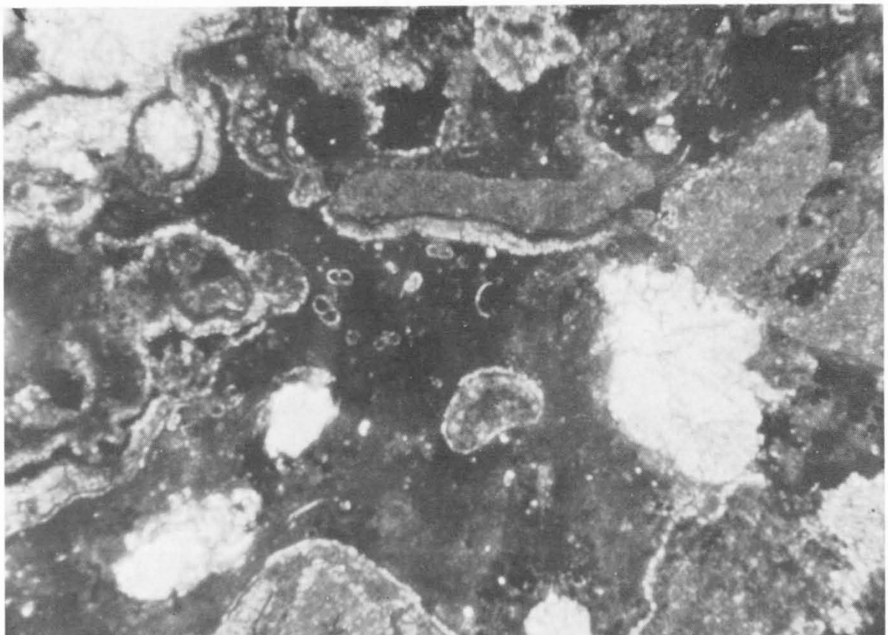


Figure 1.—Probable charophyte stem limestone from a deposit of the Austral Downs type from Aroota Bore, Tobermory, N.T. (X 15)

Figure 2.—Foraminiferal limestone breccia, Austral Downs Limestone from the junction of Manner Creek and the Georgina River, Roxburgh Downs. Foraminifera and ostracode (centre) in fine lime carbonate. (Mag. about X 15)



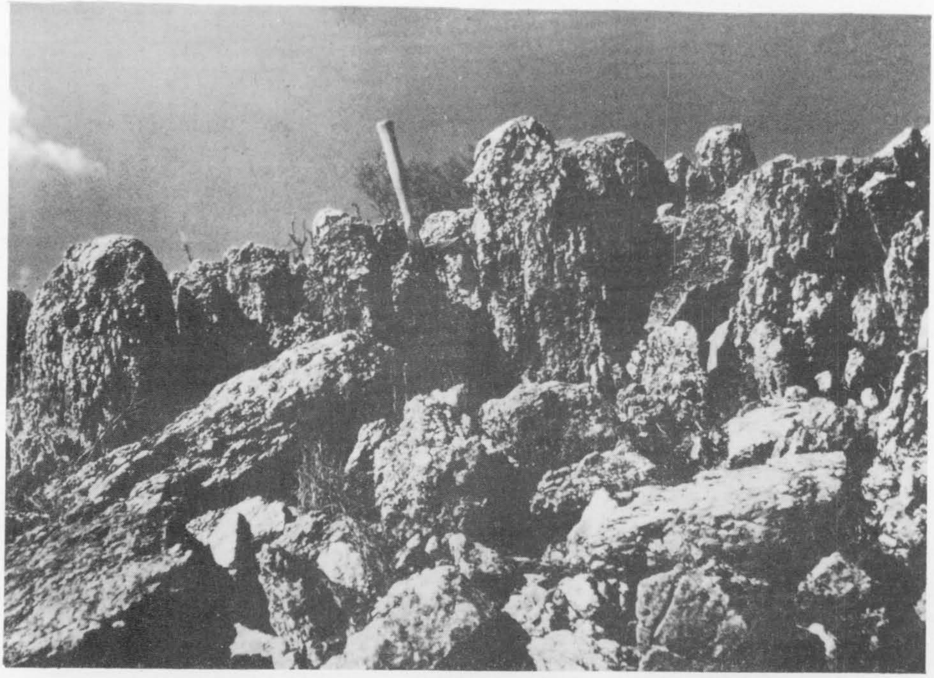
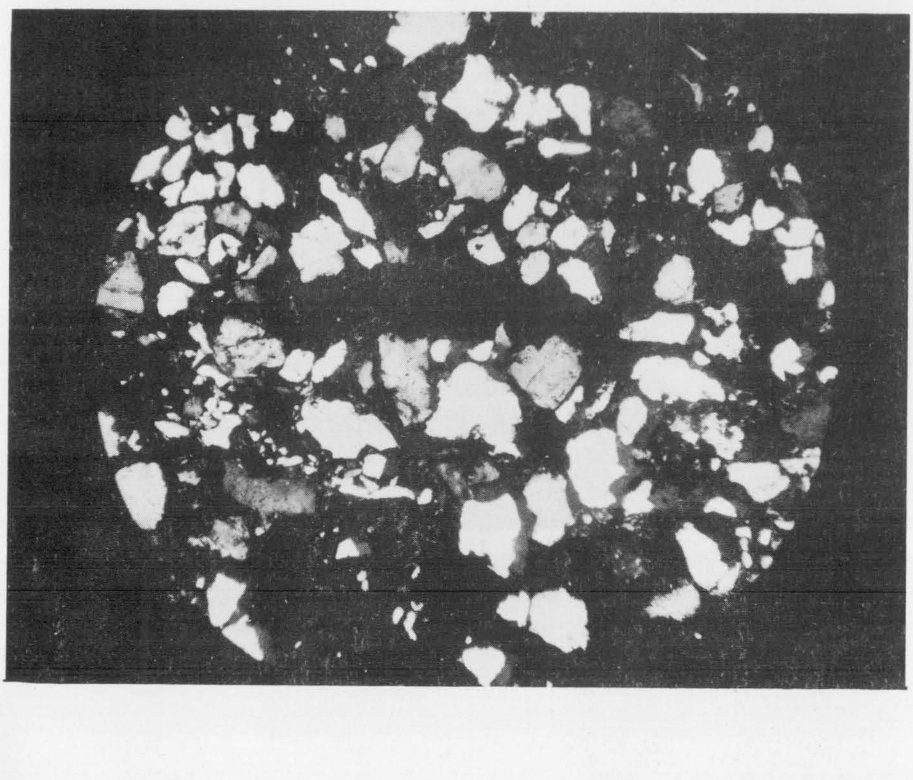
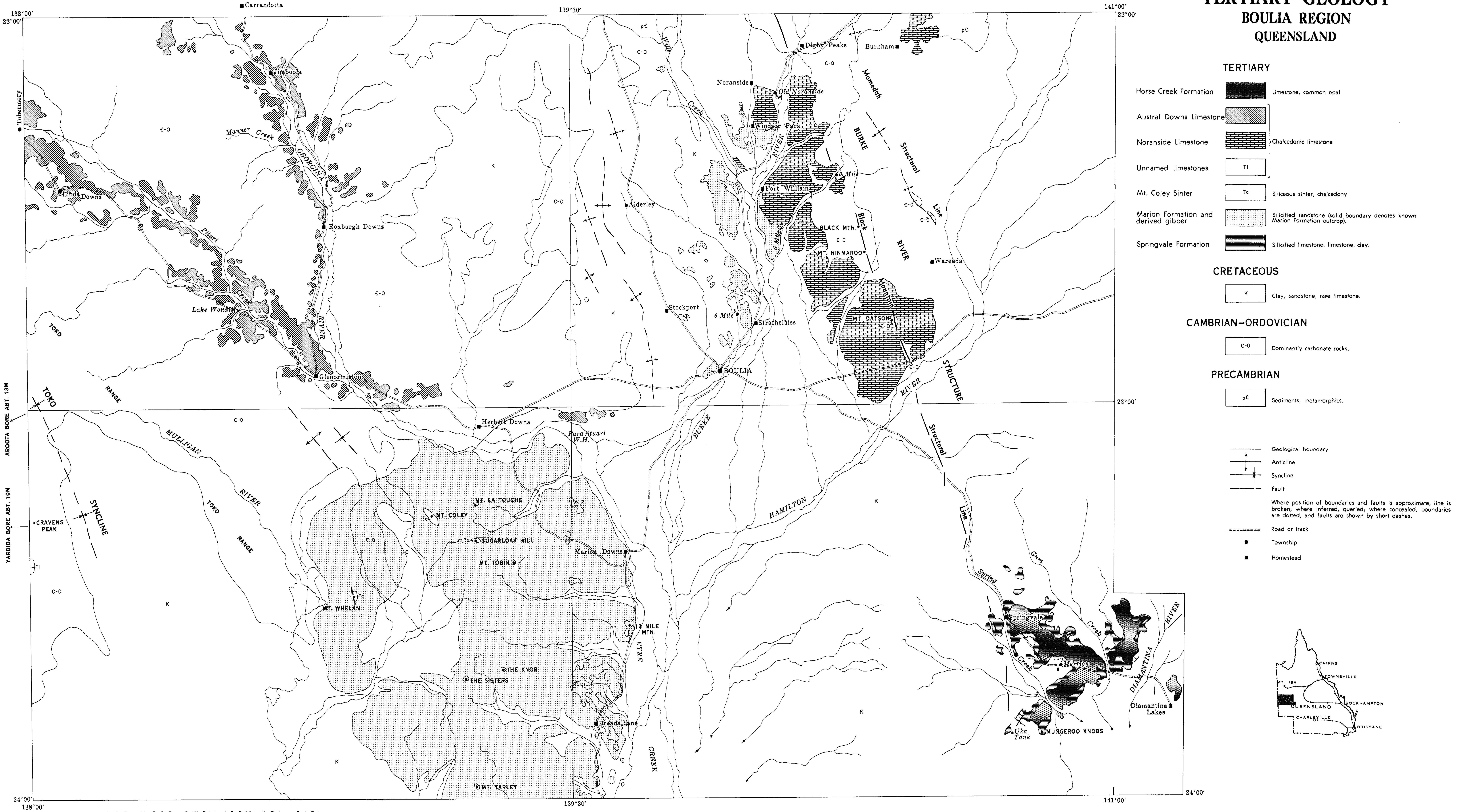


Figure 1.—Columnar billy at the top of the billy profile developed on probable Tertiary sandstone in the Orientos area, South-west Queensland

Figure 2.—Billy, 12-mile Mountain, Marion Formation. Chemically eroded quartz grains (mostly light) set in opaline silica matrix (dark). (X 45, plane polarized light)



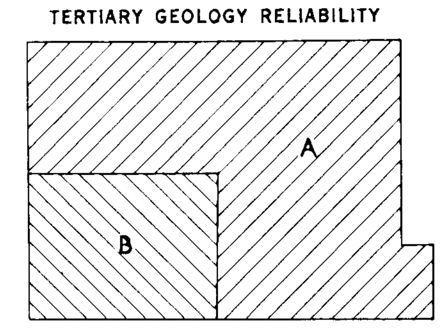
TERTIARY GEOLOGY
BOULIA REGION
QUEENSLAND



Geology by: J. N. Casey, M. A. Reynolds, D. B. Dow, P. W. Pritchard, R. R. Vine, K. G. Lucas, R. J. Paten.
Compiled by: R. J. Paten at the Geological Survey of Queensland, May, 1961.
from Bureau of Mineral Resources unpublished geological maps.

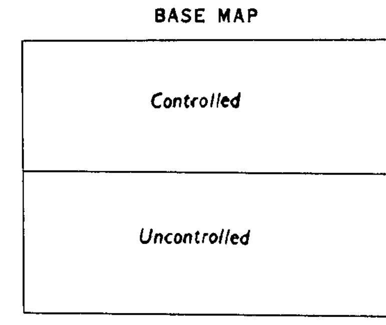
Scale
10 Miles to 1 inch
10 0 10 20 30 Miles

TERTIARY GEOLOGY RELIABILITY



A Numerous traverses with air-photo interpretation.
B Few traverses, detail sketchy

BASE MAP



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